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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101

*Test Operations Procedure 2-2-710

7 February 1984

AD No.

BALLISTIC TESTS OF ARMOR MATERIALS

	<u>Page</u>
Paragraph 1. SCOPE.	1
2. BACKGROUND	2
3. FACILITIES AND INSTRUMENTATION	2
4. REQUIRED TEST CONDITIONS	4
5. TEST PROCEDURES.	4
5.1 Resistance-To-Penetration Test	4
5.1.1 V50 Ballistic Limit.	4
5.1.2 θ 50 Ballistic Critical Angle (for Normal Distributions).	8
5.2 Resistance-to-Shock Test	9
5.3 Resistance-to-Spalling Test.	11
5.4 Behind-the-Plate Tests for Lethality Data.	13
5.5 Resistance to Penetration by HEAT Projectiles.	15
5.6 Resistance to HEP Projectiles.	17
5.7 Resistance to Mines.	17
5.7.1 Full-Scale Antitank Mine Tests	17
5.7.2 Quarter-Scale Tests.	20
5.7.3 Antipersonnel, Bounding-Type Mines	21
APPENDIX A. CRITERIA FOR ASSESSING A DEFEAT OF ARMOR.	A-1
B. ANGLE OF OBLIQUITY.	B-1
C. EFFECTS OF IMPACT ON ARMOR AND PROJECTILES.	C-1
D. MEASUREMENT OF PROJECTILE YAW	D-1
E. CONVERSION OF θ 50 CRITICAL ANGLE TO V50 BALLISTIC LIMIT	E-1
F. BALLISTIC LIMIT PREDICTIONS FROM MODELS	F-1
G. SUPPORT FOR THIN PLATES	G-1
H. BALLISTIC DATA RETRIEVAL AT ABERDEEN PROVING GROUND.	H-1
I. PROCEDURE FOR DETERMINING θ 50	I-1
J. REFERENCES.	J-1

1. SCOPE. This TOP describes the methods available for assessing the ability of armored vehicle armor to provide protection against attacking projectiles and land mines. Tests of the basic armor rather than tests of the vehicle are emphasized. Related topics covered by other TOP's are:

*This TOP supersedes TOP 2-2-710 dated 6 April 1977.

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Armored Vehicle Vulnerability to Conventional Weapons, 2-2-617^{1*}
 Resistance to Severe Shock (Armored Vehicles), 2-2-620²
 Armor Weldments, 2-2-711³
 Protection of Armored Vehicles Against Kinetic Energy Projectiles,
 2-2-715⁴
 Fragment Penetration Tests of Armor, 2-2-722⁵
 Ballistic Testing of Personnel Armor Materials, 10-2-506⁶

2. BACKGROUND. Before a specific armor type and configuration can be selected to provide the desired protection for an armored vehicle, samples of the armor must be subjected to the attack conditions anticipated. The most important of these conditions is attack by kinetic energy (KE) projectiles. Over the years, much effort has been directed toward developing the optimum sampling technique (e.g., the velocities at which projectiles are fired) to provide a quantitative measure of the capability of armor to resist perforation by KE projectiles. The most significant of these techniques are included in this TOP. Also important, but requiring less sophisticated testing, are evaluations of armor resistance to attack by high-explosive antitank (HEAT) projectiles, high-explosive (HE) projectiles, high-explosive plastic (HEP) projectiles, land mines, and projectile fragments. All of these except projectile fragments are covered in this TOP.

In addition to the concern about whether a certain type of attack will or will not defeat an armor target, it is important in the case of defeats to know to what extent the armor was defeated. This determination involves an appraisal of behind-the-plate lethality in terms of the damaging potential of armor fragments displaced to the rear of the plate and of projectile fragments that pass through the plate.

Test samples can be in the form of flat plates (either rolled, cast, or welded), forgings, extrusions, castings, angular welded joints, spaced armor arrangement, or composites. The materials currently being used or developed for armor applications include steel, aluminum, titanium, ceramics, glass, nylon and other fabrics, and plastics, as well as composite and spaced arrangements of these materials.

An exhaustive discussion of armor and armor testing is contained in DARCOM-P 706-170.

3. FACILITIES AND INSTRUMENTATION.

3.1 Facilities.

<u>ITEM</u>	<u>REQUIREMENT</u>
Firing ranges	Various, to 100 m long, both open and enclosed. One open range 200 m long
Projectiles: AP, ball, fragment-simulating, HE, HEAT, HEP, plate proofing and appropriate weapons	Indicated by test directive or specification

*Footnote numbers correspond to references in Appendix J.

<u>ITEM</u>	<u>REQUIREMENT</u>
Cooling chamber (liquid CO ₂ or mechanical); dry ice when required (para 5.2.3 and 5.7)	-46° C (-50° F) capability
Slotted supports or "butts" for holding test plates securely at desired obliquity	Discussed in Appendix B
Backup support for thin plates	Described in Appendix G
Quarter-scale mine test facility	Described in para 5.7.2
Witness plates: steel aluminum alloy	Indicated in para 5.5.2 Described in Appendix A para 2c
Cameras: high-speed Polaroid	Indicated in para 5.4.2 Described in Appendix D para 2
Special velocity panel and recovery medium for lethality test	Described in para 5.4.2
Flash radiographic units for testing lethality (para 5.4), resistance to HEP projectiles (para 5.6), and yaw when appropriate (Appendix D para 4)	Described in TOP 4-2-825 ⁸

3.2 Instrumentation.

<u>ITEM</u>	<u>MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*</u>
Thermocouples with potentiometer or recorder for mine tests (para 5.7)	$\pm 1^{\circ}$ C (2° F)
Velocity-measuring instrumentation (TOP 4-2-805 ⁹)	Velocity to 1,700 m/s $\pm 0.1\%$ (5,600 fps)

4. REQUIRED TEST CONDITIONS.

a. In preparing to test armor, establish the correct plate obliquity, taking into account such factors as compound obliquity, compensation for different heights of gun barrel and target, and angle of fall of projectile at simulated ranges, all of which are discussed in Appendix B.

*Values can be assumed to represent ± 2 standard deviations; thus, the stated tolerances should not be exceeded in more than 1 measurement of 20.

b. Before firing takes place, the type of ballistic limit to be determined must be established (Appendix A). The data to record regarding plate and projectile damage must also be established (Appendix C). Early ammunition firings should determine whether yaw will be a problem (Appendix D).

5. TEST PROCEDURES.

5.1 Resistance-to-Penetration Test. The resistance-to-penetration test measures the ability of armor to withstand attack by KE projectiles or simulated projectile fragments. This property is determined by firing projectiles at the armor target and varying the conditions from round to round in an effort to determine those critical conditions wherein there is an equal probability of defeating the target and not defeating the target; i.e., $P(D) = 0.5$. To express this property quantitatively, it is necessary first to define what constitutes a defeat of the armor (Appendix A) and second to describe the firing procedure employed (para 5.1.1).

5.1.1 V50 Ballistic Limit. The V50 ballistic limit (in m/s) is the usual means of expressing the ballistic protection property of armor. It is obtained by holding the thickness and obliquity of the armor target constant while varying the projectile velocity from round to round by adjusting the weight of propellant. To be successful, the projectile-target combination must produce a transition from partial to complete penetrations, as the velocity increases, that can be modeled by the cumulative normal (Gaussian) distribution. If enough rounds are fired, two parameters, the mean and standard deviation, can be determined for each ballistic test; they are referred to as the V50 ballistic limit and the standard deviation, both expressed in meters per second. The standard deviation is a measure of the data spread or the steepness of the curve. The methods described in paragraphs 5.1.1.1, 5.1.1.2, 5.1.1.3, and 5.1.1.5 assume the distribution to be normal, while the method of paragraph 5.1.1.4 assumes that the data will not fit the normal curve. A detailed description of this subject is contained in references 7, 10c and h, and 11b (Appendix J). A typical normal distribution curve derived from firing data is shown in Figure 1.

Figure 1 shows that over a range of velocities, some of the projectiles will completely penetrate (i.e., perforate) the armor, and the remainder will not. This phenomenon gives rise to the zone of mixed results, which can be defined as that range of velocities in which both complete and partial penetrations can be obtained. Theoretically, this zone could extend from the point where the cumulative normal curve approaches zero to the point where it approaches 1.0. In practice, however, a zone of mixed results is considered to exist only if a partial penetration occurs at a higher velocity than at least one complete penetration. The zone of mixed results is, then, the difference in velocities between the highest partial penetration and the lowest complete penetration actually obtained.

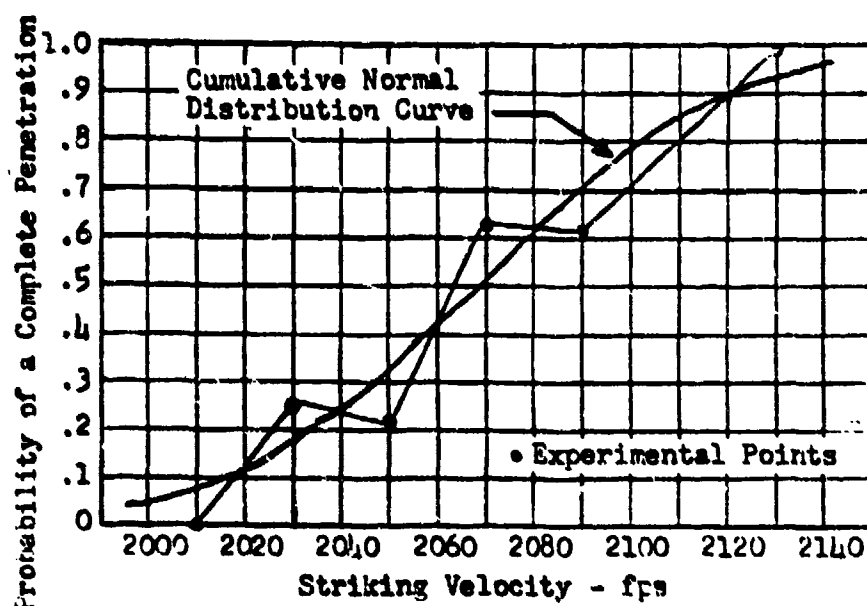


Figure 1. Typical distribution of complete penetrations in ballistic tests of armor for a V50 ballistic limit of 631 m/s (2,069 fps).

5.1.1.1 Up-and-Down Method (for Normal Distributions). This method is the one most used historically for ballistic development and acceptance tests of armor and is still used when the zone of mixed results is considered reasonably small or can fairly well be estimated. (When the zone of mixed results is of uncertain size, the Langlie method described in 5.1.1.2 is preferred.) The up-and-down method is the most efficient in terms of projectiles used. The first round to be fired in this method is prepared with a propellant charge estimated to give a striking velocity equivalent to the ballistic limit of the target. If the resulting impact is a partial penetration, the second round is prepared with a propellant charge estimated to increase the velocity by 30 m/s (100 fps) (or more if a large jump is obviously needed). If this round results in a complete penetration, the third round is loaded with a propellant charge estimated to decrease the velocity by 15 m/s (50 fps). The velocities of subsequent rounds are increased by 15 m/s each time a partial penetration occurs, and decreased by 15 m/s each time a complete penetration occurs, until the conditions of the test are satisfied. If the first round had been a complete penetration, the second round would be prepared with a propellant charge estimated to reduce the velocity by 30 m/s (or more if required), etc. Increments (or decrements) of no less than 30 m/s are used at the beginning until a reversal occurs (from partial to complete or vice versa), after which 15-m/s increments or decrements are used. The following varieties of the up-and-down method are commonly used in determining the V50 ballistic limit of armor:

a. One complete penetration and one partial penetration within a velocity spread of 15 m/s - A ballistic limit obtained by this method is not very accurate. This method should be used only when the target area or the number of projectiles is limited. Firing is discontinued as soon as a partial penetration is obtained at a striking velocity that is below, but within 15 m/s of, the lowest striking velocity that produced complete penetration. (To expedite this process, successive firings at velocities halfway between those that produced the existing complete and partial penetrations are usually used.) These two striking

velocities are then averaged to obtain the ballistic limit. When this method is used, it is recommended that a confirming partial penetration be obtained. This type of ballistic limit is referred to as a two-round ballistic limit.

b. Two complete penetrations and two partial penetrations within a spread of 18 m/s (60 fps) - This method is used in acceptance tests of armor or in cases when minimal target area limits the number of rounds that can be fired (referred to as a four-round ballistic limit).

c. Three complete penetrations and three partial penetrations within a spread of 27, 38, or 46 m/s (90, 125, or 150 fps) - A ballistic limit determined by this method is reasonably accurate. This type (referred to as a six-round ballistic limit) is used most in that it generally is used in all tests involving small arms projectiles. Firing is discontinued as soon as three complete and three partial penetrations are obtained within a velocity spread of 27, 38, or 46 m/s, as specified. These six striking velocities are then averaged to estimate the ballistic limit. The velocity spread employed will depend on specifications or other requirements. Reference 10h (Appendix J) can be used as a guide to determine maximum velocity spread when it is not specified.

d. Five complete penetrations and five partial penetrations within 38 or 46 m/s - This method provides ballistic limits of relatively high accuracy; it is usually employed in tests involving small arms projectiles or personnel armor. Firing is discontinued as soon as five complete and five partial penetrations are obtained within a velocity spread of 38 or 46 m/s, as specified. These 10 striking velocities are then averaged to estimate the V50 ballistic limit.

If, in attempting to obtain a ballistic limit by the above method, the striking velocity spread between the round causing a low complete penetration is more than 38 m/s (or 46 m/s, if so prescribed) below a round causing a partial penetration, the ballistic limit is based on 10 velocities comprising the five lowest striking velocities that resulted in complete penetrations and the five highest striking velocities that resulted in partial penetrations, regardless of the spread. In such instances, it is usually necessary to fire a dozen or more rounds before the required results are obtained. Firing is terminated as soon as the 10 required rounds have been accumulated.

5.1.1.2 Langlie Method (for Normal Distributions). Ballistic limits obtained by the Langlie method can require more rounds than the methods in 5.1.1.1 a, b, and c above, and about the same as the method in 5.1.1.1.d. The ballistic limit accuracy should, therefore, be about the same as that of 5.1.1.1 d. This method is employed when uncertainty exists regarding the plate-projectile interaction and the size of the zone of mixed results. The technique assures that a large percentage of the zone of mixed results is explored. It is also employed when a greater degree of accuracy is desired than can be obtained by other less costly methods. Reference 12 (Appendix J) provides the theoretical development. Below is the application to ballistic testing. To conduct this test, the test director must take the following specific actions:

a. Select a lower and upper projectile velocity limit (gates) so that the probability of obtaining a complete penetration at the lower velocity or a partial penetration at the upper velocity is highly unlikely.

b. Fire the first round at a velocity midway between these two limits.

c. If the first round results in a complete penetration, drop the velocity of the second round halfway between the first round velocity and the lower limit velocity; if a partial penetration, raise the velocity of the second round halfway between the first and upper limit velocity.

d. If the first two rounds result in a reversal (one partial, one complete), fire the third round midway in velocity between the velocity of the first two rounds. If the first two rounds result in two partials, fire the third round at a velocity midway between the second round velocity and the upper limit velocity. If the first two rounds result in two completes, fire the third round midway between the second round velocity and the lower limit velocity.

e. Fire succeeding rounds using the following rules:

(1) If the preceding pair of rounds resulted in a reversal (one partial, one complete), fire at a velocity midway between the two velocities.

(2) If the last two rounds did not produce a reversal, look at the last four rounds. If the number of completes and partials is equal, fire the next round midway between the velocity of the first and last round of the group. If the last four did not produce equal numbers of partials and completes, look at the last six, eight, etc., until the number of partials and completes is equal. Always fire at a velocity midway between the first and last round of the group examined.

(3) If the conditions in (2) above cannot be satisfied and the last round fired resulted in a complete, fire the next round at a velocity midway between the last round and the lower velocity limit; otherwise (last round is a partial), midway between the velocity of the last round and the upper limit.

(4) Continue as in (1) and (2) above until the requirement for rounds has been met; i.e., 12 rounds unless otherwise specified.

f. If the firing does not produce a zone of mixed results, compute V50 by averaging the lowest complete and highest partial.

g. If the firing produces a zone of mixed results, compute V50 and standard deviation by using the cumulative normal and the principle of maximum likelihood. A computer program is available at Aberdeen Proving Ground (APG) for this purpose (ref. 10e, Appendix J).

h. In cases in which it becomes obvious after a few rounds have been fired that the estimated V50 was too high or too low, a readjustment of this estimate can be made along with newly selected upper and lower gates. Then continue firing as prescribed. This process results in a slightly more accurate determination of the ballistic limit and, more importantly, the estimated standard deviation calculated from the data is likely to be more representative of the actual standard deviation.

5.1.1.3 Sampling-of-Levels Method (Distribution Not Normal). Not all projectile-plate interactions can be modeled to the cumulative normal (ref. 10c, Appendix J). In these cases, the above procedures are not applicable and the sampling-of-levels method should be used. (This method has sometimes been referred to as the binomial method since for each trial there are only two possible outcomes -

partial penetration or complete penetration). In this test, a fixed velocity and obliquity are used and a group of rounds fired at the plate. A point estimate of the probability of penetration is computed at each velocity level by determining the ratio of complete penetrations to the number of rounds fired. Groups of projectiles are fired at several velocities to determine how the probability of complete penetration varies with velocity. The number of rounds fired at each velocity level depends wholly on the level of protection and the confidence one desires in the results.

5.1.1.4 Probit Design (for Normal Distributions). The probit design of test involves a number of trials at each of several preset levels of severity, and as such is similar to the sampling-of-levels method. The difference is that the term "probit design" is referred to in the literature as applying only to normal distributions; the sampling-of-levels method (a term devised at APG) is used for distributions that are not normal. Figure 1 was derived from data obtained from a probit design of test.

5.1.2 θ 50 Ballistic Critical Angle (for Normal Distributions). The θ 50 ballistic critical angle is determined only when it has advantages over the more common V50 ballistic limit. It is expressed in obliquity of the target plate, in degrees, at which the probability of effecting a complete penetration is 50%. It is obtained by holding the velocity of the projectile and the plate thickness constant and varying the obliquity of the armor from round to round. To be successful, the projectile-target combination must produce a transition from partial penetrations to complete penetrations, as the obliquity decreases, that fits a cumulative normal distribution. Thus, the curve would look like that of Figure 1 except that the abscissa would be labeled "plate obliquity - degrees" and might range, for example, from 25° to 35°. For this test, use a target fixture that accommodates various target plate obliquities and permits the use of high-speed flash radiography (Appendix D, para 4) to determine projectile performance upon impact.

In the θ 50 determination, the up-and-down or the Langlie method of changing conditions between each trial is applied to the obliquity of the target plate rather than to velocity. Detailed procedures for obtaining θ 50 by the Langlie Method are contained in Appendix I. The occasions when it can be desirable to consider making a θ 50 critical angle determination rather than a V50 determination are as follow:

a. The projectile has components, such as discarding sabots or fins, which cannot function properly at velocities below standard muzzle velocity, and thereby induce unacceptable projectile yaw. In this case, the target would be placed at the desired range and all projectiles fired using the standard propellant weights. This application constitutes most of the uses of the θ 50 technique. Since this application requires very large targets and is time-consuming, it should not be used unless proof has been obtained, using yaw cards, that the projectile is unstable if fired at close-in targets using reduced propellant weights.

b. The rounds, as received, are fully assembled and no facilities are available for reloading the propellant on a round-by-round basis.

c. There is a requirement to fire at a range where the downward trajectory of the projectiles will be an important factor regarding penetrating ability of

the projectile. In many cases, however, this condition can easily be simulated in a V50 test by making an obliquity correction to a close-in plate equal to the angle of fall of the projectile at the desired range. When this can be done, the V50 test is preferred.

d. The test directive specifies the use of the $\theta 50$ method using close-in targets and the firing of projectiles at a less-than-standard fixed propellant weight that will produce a projectile velocity for any range of interest. In using this application, it is possible to load the propellant for each round in advance and thereby eliminate the need for standby ammunition-loading personnel.

e. No information is available on velocity of the projectile at down-range locations, making it impossible to simulate range by reducing muzzle velocity.

The disadvantages of the $\theta 50$ method are:

a. The $\theta 50$ test requires a facility that can easily change obliquity. This is not difficult for small arms projectiles but becomes a major facility problem with antitank projectiles.

b. A single $\theta 50$ determination is rarely meaningful since velocity to defeat a given target has more significance to most engineers than obliquity at which a plate must be placed to defeat a projectile.

A family of $\theta 50$ values, using a specific projectile, can readily be converted to a family of V50 values by interpolation of graphs of the former. This procedure is shown in Appendix E.

5.2 Resistance-To-Shock Test.

5.2.1 Characteristics. The resistance-to-shock of armor is its ability to absorb, without cracking or rupturing, the energy resulting from the impact of a solid projectile or from the explosion of a high-explosive material. The shock resistance of armor is evaluated by the amount of cracking that develops on a plate under defined impact conditions. In some cases, the evaluation is based upon the striking velocity required to produce a specified degree of cracking, usually the first sign of cracking. In shock tests, no attempt is made to perforate the armor.

5.2.2 Projectiles. The projectiles used for this test are either plate-proofing projectiles (soft, deformable, flat-nosed, steel or aluminum projectiles which mushroom upon impact), HE point-detonating projectiles, or HEP projectiles. The severity of the test is a function of striking velocity and weight of the round for KE projectiles, and striking velocity and weight and type of explosive material for HE rounds. Tests with plate-proofing projectiles are conducted at 0° obliquity. The results of such a test are shown in Figure 2. Resistance-to-shock tests with HE projectiles are conducted either at 0° or at some other low obliquity.

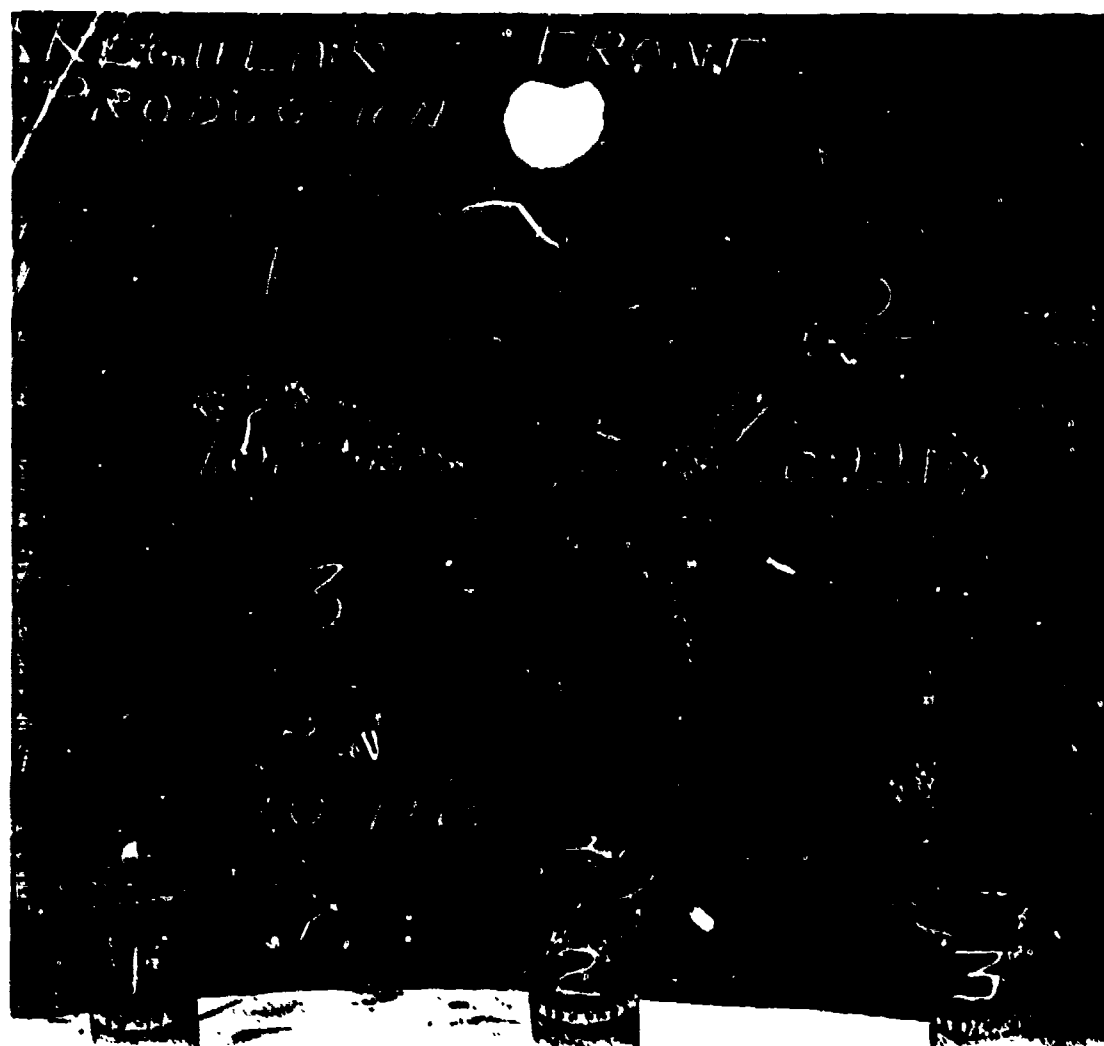


Figure 2. Typical results of resistance-to-shock test of production steel armor.

5.2.3 Laboratory Testing. In determining the ability of steel armor to withstand shock, laboratory testing using the Charpy impact test at minus -40°C (40°F) precedes the ballistic shock test described in 5.2.1 above. Consequently, aside from tests of weldments, ballistic resistance-to-shock tests are usually limited to certain low temperature tests, special types of armor, and some thin, face-hardened, steel armor plates. The explosion-bulge test, designed mainly for evaluating the crack susceptibility of weldments, is a laboratory test also suitable for shock-testing unwelded armor plate. This test is described in TOP 2-2-711. Consideration should be given to using this test whenever a ballistic shock test of armor material is desired.

5.2.4 Field Testing. Plate-proofing projectiles are available in the following sizes: 37-mm, 57-mm, 75-mm, 90-mm, and 105-mm. HE projectiles of calibers ranging from 20 mm to 105 mm can likewise be considered suitable for shock tests, but would ordinarily be employed only when available plate-proofing projectiles are not suitable for imparting the desired amount of shock to the armor or when HE tests are desired to corroborate results obtained with plate-proofing projectiles. For tests of steel armor 13 mm (1/2 in.) thick or lighter, HE projectiles are used. Plate-proofing projectiles are favored for resistance-to-shock tests because the fuse functioning of HE projectiles introduces a control problem. Uncontrollable variations in fuse delay, between the time the projectile strikes the armor and the time the fuse functions, can influence the amount of shock and the resultant damage to the plate.

5.3 Resistance-to-Spalling Test.

5.3.1 Characteristics. The resistance-to-spalling test (also known as the projectile-through-plate or PTP test) is performed to detect defects in steel quality and heat treatment. These defects, principally laminations and lack of toughness, tend to promote the displacement of spall from the back surface of a plate (fig. 3). Spalling is highly undesirable since it results in the projection of many additional destructive fragments within an armored vehicle.

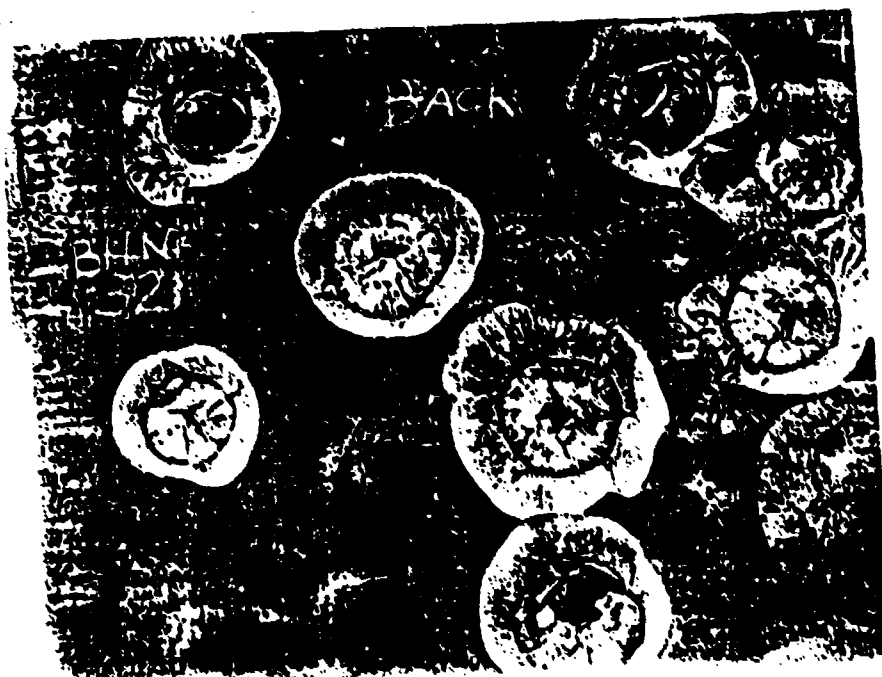


Figure 3. Poor-quality steel armor showing excessive backspalling and plate cracking.

5.3.2 Procedure.

a. The established practice in testing armor for susceptibility to spalling is to fire an armor-piercing (AP) projectile at a velocity that will result in the passage of the projectile completely through the plate (Navy complete

penetration) even though spalling can occur under a less severe attack. The full spalling potential of the armor will not otherwise be realized, and inconsistent results are more likely to occur. The projectile is fired to strike the plate at normal (0°) obliquity to promote reproducibility of results and to ensure that the projectile remains intact. Usually, a projectile is selected whose diameter is the same as or slightly greater than the thickness of the armor to be tested. Typical resistance-to-spalling tests have been used historically for rolled homogeneous steel armor using the weapons, projectiles, and velocities shown in Table 1.

TABLE 1 - TYPICAL TEST CONDITIONS FOR RESISTANCE-TO-SPALLING TESTS ON ROLLED HOMOGENEOUS STEEL ARMOR - FIRING OBLIQUITY 0°

Armor Thickness		Weapon	Projectile Velocity*	
mm	in.		m/s	fps
16 \pm 3 mm	1/2 to $<3/4$	20-mm AP M95	760 to 775	2500 to 2550

*Generally 60 m/s (200 fps) above the V50 BL.

b. The results of the resistance-to-spalling test are expressed in terms of the average exit diameter and the percentage by which the "through" hole is surrounded by spalled armor (fig. 4). Specifications covering this type of test permit rejection on the basis of both excessive average exit diameter and excessive cracking (cracked beyond radius of two diameters of the projectile) developed within 24 hours of the test.

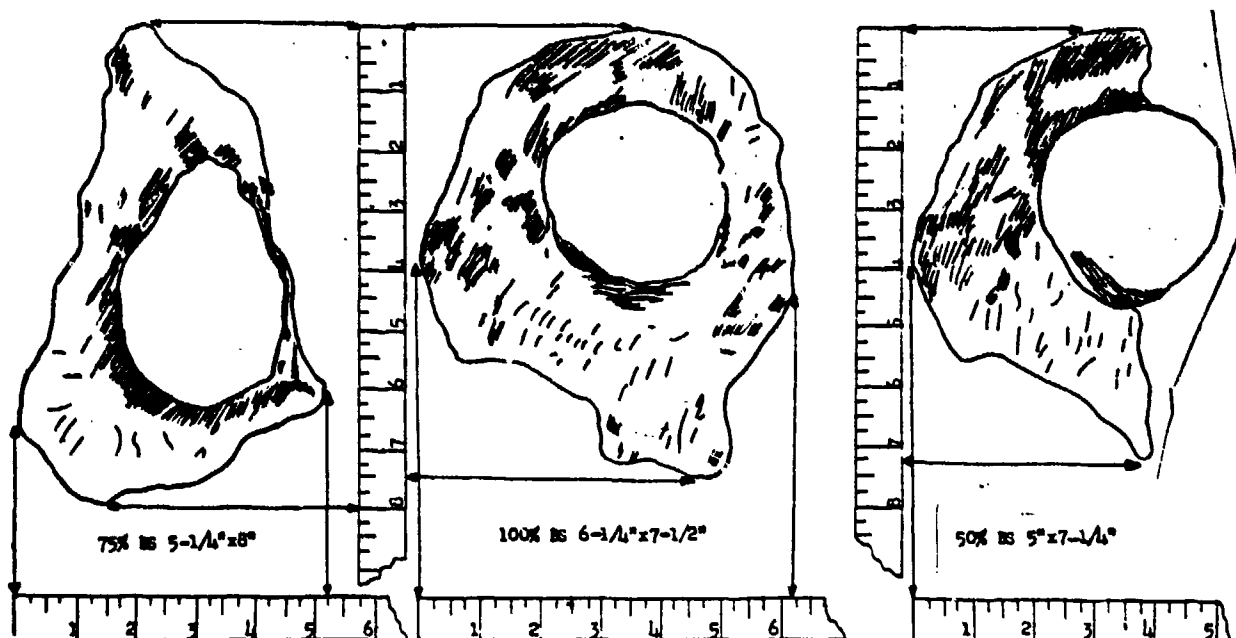


Figure 4. Methods of determining dimensions on backspalls.

5.4 Behind-The-Plate Tests For Lethality Data.

5.4.1 Characteristics. Behind-the-plate lethality tests are usually performed on steel plates less than 25 mm thick or samples of fabric or plastic armor. AP projectiles, fragment-simulating projectiles, right cylindrical projectiles, or cubes are fired at the target. The projectiles are fired at velocities high enough to cause fragments to pass beyond the back of the target. The velocities of the fragments can be measured. The number and distribution pattern of the fragments are determined. The depth of penetration of the fragments in gelatin or Celotex is measured and fragments are recovered and weighed. In some programs, the velocity level of the projectiles can be varied, and the effect on the number of fragments thrown, their distribution, penetration depth, and mass is observed.

5.4.2 High-Speed Camera Technique. An example of one of the test setups is illustrated in Figure 5. Projectile striking velocities are measured using printed circuits located about 5 m (15 ft) from the weapon, and associated chronographic equipment. The high-speed camera is located so that the moment of impact on the plate is recorded, along with the instant at which each fragment thrown pierces the gridded black leatherette behind the plate. The latter is made possible by the lights indicated in the figure. These illuminate each hole made in the leatherette instantaneously. A silvered leatherette a few inches behind the black assists by reflecting the light back through the holes. The light sensitizes the camera film whose running speed is known and upon which a space scale is marked. Thus, the time of flight of the fragment from the moment of impact with the plate to the moment it pierces the screen can be computed. The distance from the impact on the plate to each fragment hole in the black leatherette is measured. The average fragment velocity can then be computed. The fragment distribution is clearly captured on the black leatherette. A 50- by 50- or 75- by 75-mm (2- by 2- or 3- by 3-in.) grid is painted on the leatherette (upholsterer's plastic), and the horizontal and vertical axes are marked with numbers and letters, respectively. Thus, the location of each impact is defined by the grid coordinates. The point of impact of the projectile on the plate is projected on the leatherette. This allows an analysis of the distribution using the point of impact as the origin. The rear silvered leatherette facilitates tracing the fragment path to the gelatin. Wires fed through holes in the front and back leatherettes positively identify the point of impact of the fragment in the gelatin. The depth that each fragment penetrates the gelatin or Celotex is measured. The fragments are recovered from the gelatin or Celotex and each fragment is weighed.

5.4.3 Printed Circuit Technique. Printed circuits, spaced a short distance apart behind the target, can be used for measuring residual velocity of a projectile when it is fairly certain that the projectile will pass through the target without pushing fragments ahead of it that would strike the printed circuits first. Otherwise, the velocity of the leading fragment will be obtained which has limited usefulness. When fragments are expected, witness material such as Celotex or Nuwood is placed behind the printed circuits to determine the distribution of fragments and to recover fragments for determining depths of penetration and weights.

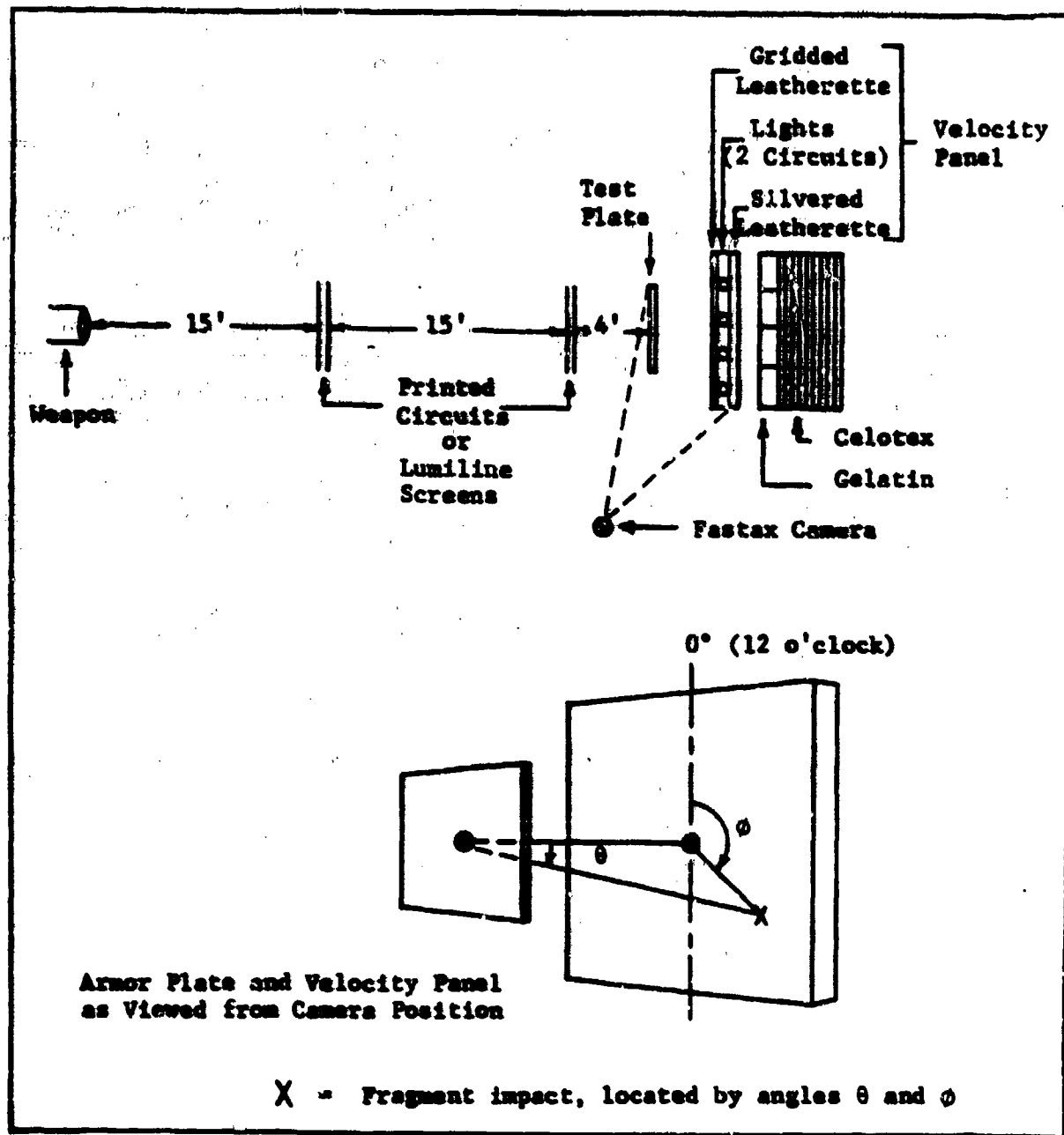


Figure 5. Test setup for fragment distribution studies.

5.4.4 Radiographic Technique. The radiographic technique for studying lethality of behind-the-plate fragments involves the use of orthogonal pairs (90° apart) of flash radiographic units, one pair being located directly behind the plate and another pair located 0.3 m or so (typically, 36 cm (14 in.)) beyond that. The radiographic units are triggered to record fragment images on film, from which velocities can be computed and areal distribution and fragment sizes determined. Place 13-mm (0.5-in.) wallboard farther down range to assist in making distribution determinations. The velocity and yaw of the attacking projectile just before impact can also be determined with an additional two pairs of orthogonal radiographic units viewing an area in front of the target. Greater details on this technique can be obtained from reference 10a and TOP 4-2-825 (Appendix J).

5.5 Resistance To Penetration By Heat Projectiles.

5.5.1 Characteristics. High-explosive antitank (HEAT) rounds, also called shaped charge ammunition, form a high-velocity jet of fragments that penetrates metallic armors and other materials. The jet is initiated on impact with the target or other sufficiently dense material by a fuze which starts the explosive action. Unlike the penetrations by KE projectiles, the striking velocity of the HEAT projectile has little effect on the depth of penetration by the jet. The value of the jet is its high penetrating ability and its high potential lethality once it has penetrated armor even though its diameter is often comparable to that of an ordinary lead pencil.

Studies have been conducted to compute penetration variables for shaped charge jets (ref. 7a). Since the penetration produced by the jet varies from round to round, a statistical sample, say 5 to 10 rounds, is desirable to determine average penetration. Various armor materials and armor arrangements have been tested to determine their ability to defeat HEAT projectiles. Test programs have been conducted on aluminum alloy, rolled and cast steels, titanium, polyethylene, other armor materials, combinations of materials, and spaced and barred armor configurations. Tests of this type involving tank hull castings and turret castings are of special interest.

HEAT projectiles are designed to perform best when the warhead functions at what is called built-in (or ogive) standoff (fig. 5). Such functioning occurs only if the fuze acts instantaneously when the point of the ogive strikes the target. Any hesitation in fuze functioning, which is sometimes caused by very high obliquity targets, will reduce the effectiveness of the projectile.

5.5.2 Test Procedures. Both static and dynamic tests can be conducted. In dynamic tests, the projectile is fired from a gun. In static tests, the projectile is held in position at the required obliquity against the target and detonated. Projectile alignment for static detonation is accomplished by use of a precision-made plywood cradle and a warhead simulator with a dowel pin projecting from the center to simulate the jet. The simulator has a built-in level and a device for measuring obliquity. The pin that simulates the jet permits pin-point accuracy for the impact point. After the simulator is properly positioned, it is removed from the plywood cradle and replaced with the actual munition which destroys the cradle upon detonation.

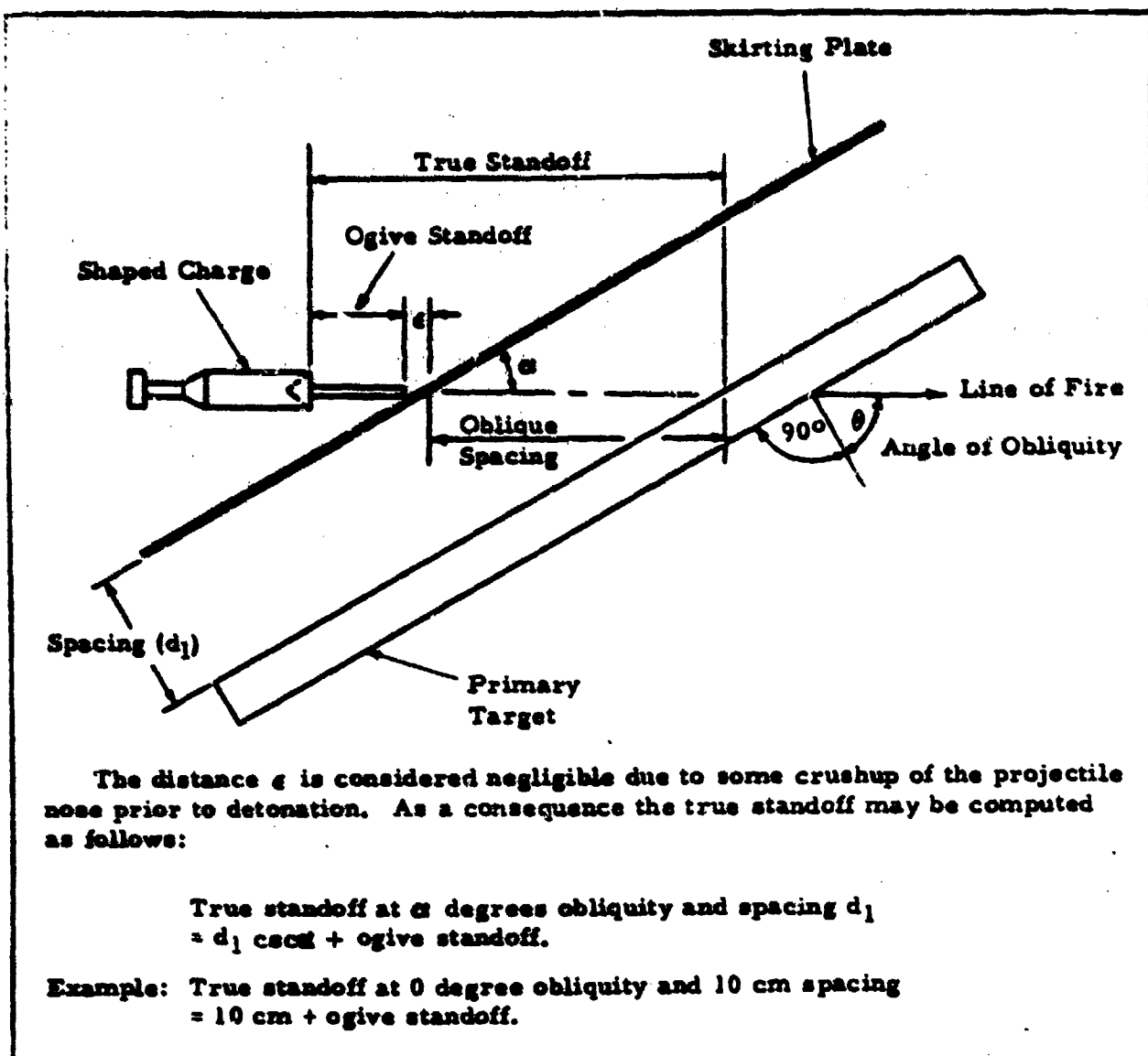


Figure 6. Computation of true standoff for a spaced armor arrangement attacked by shaped charge projectiles.

Usually, a specific-caliber HEAT round, such as a 3.2-in. BRL precision shaped charge, is used on a particular test; more than one type round can be used, however, the number depending on test requirements. Some other HEAT rounds used are 5-in. BRL precision shaped charge, special 105-mm HEAT projectiles, and 3.5-in. rocket. In both static and dynamic tests, 25-mm-thick mild steel witness plates are often stacked behind the impact area. When complete penetration of the target is achieved by the jet, its residual energy is expended in penetrating the witness plates. The depth of penetration into the plates is measured and can be equated with penetration into a standard material such as specification rolled steel.

If a tank hull or turret is to be tested, a "square" grid is painted on the test area and each square is identified. Measure the thickness at which the round is to be impacted and the firing obliquity. After the round is fired, a careful examination of the impact damage is made and all pertinent data such as type penetration (partial or complete), amount of spalling or cracking, etc., are recorded. Some tests require a study of fragment distribution for lethality studies. In these cases, a witness packet is used to assess angular dispersion, depth of penetration, and fragment size. This witness packet can be made of celotex insulation board or laminated sheet metal, plywood, and celotex.

Tests of spaced armor (usually a skirting plate, an air space, and the main armor) are frequently planned from "standoff versus penetration" curves that have been developed for a particular round. Spaced armor has the effect of increasing the standoff to a point that reduces the penetrating ability of the projectile. The true standoff distance as related to tests of spaced armor against shaped charge attack is illustrated in Figure 6. The standoff-penetration curve gives the expected depth of penetration in a given armor material for various standoff distances using a specific type of shaped charge ammunition. This assists in estimating the best conditions for the test at hand. In some instances, tests against armor with shaped charge ammunition can be conducted from a flank angle against an armor target at obliquity. In such cases, it is necessary to consider the composite obliquity and the resultant spacings for spaced armor.

5.6 Resistance To HEP Projectiles. A HEP projectile is a major-caliber, high-explosive projectile containing a plastic explosive and a base-detonating fuze. Upon impact with a hard target, the projectile crushes and functions when the fuze impacts the target, thereupon detonating the plastic explosive. The detonation, which occurs on the face of the target, creates high blast pressures that can severely damage tank components in the vicinity of the impact. In addition, the blast generates a shock wave in the target which travels to the rear face where it develops a tensile stress that often causes severe backspalling that can damage the interior of the tank. The degree of spalling depends upon the plate material and thickness and impact obliquity.

Spalling from HEP rounds can be prevented by a skirting plate which will cause premature functioning of the fuze.

The projectiles are fired at velocities to simulate ranges of interest. The usual test objectives are to determine whether the armor targets under consideration will prevent backspall and how damaging backspall is if it occurs. Velocities of backspalls can be measured using flash radiographic units.

5.7 Resistance To Mines.

5.7.1 Full-Scale Antitank Mine Tests. The effectiveness of mines is affected by soil condition (ref. 10b, Appendix J); thus, for every mine test or simulated mine test, the type and condition of the soil in which the mine is to be buried must first be determined. A new location is preferred for each detonation, but if several mines must be detonated in the same location, the soil must be properly compacted each time. Overburden is always loose, however. A more complete discussion on this matter is in TOPs 2-2-617 and 4-2-505.¹¹

Plates submitted for mine testing are prepared for testing by fabricating a "crack starter" on the plate. The crack starter is a 50- by 50- by 75-mm block

fillet-welded in the center of the plate to simulate a component welded to a vehicle floor plate. A typical test setup is shown in Figure 7. The test plate with the crack starter on the upper surface is supported under a heavy frame. The plate is positioned parallel to the ground at a height simulating the distance from the ground to the floor plate of the vehicle in which it is to be used. The mine is buried beneath the center of the plate, generally at a depth that will allow covering it with 100 +25 mm (5 in.) of loose earth. The mine is then statically detonated, and the effect on the plate and crack starter is inspected to evaluate the level of protection afforded.

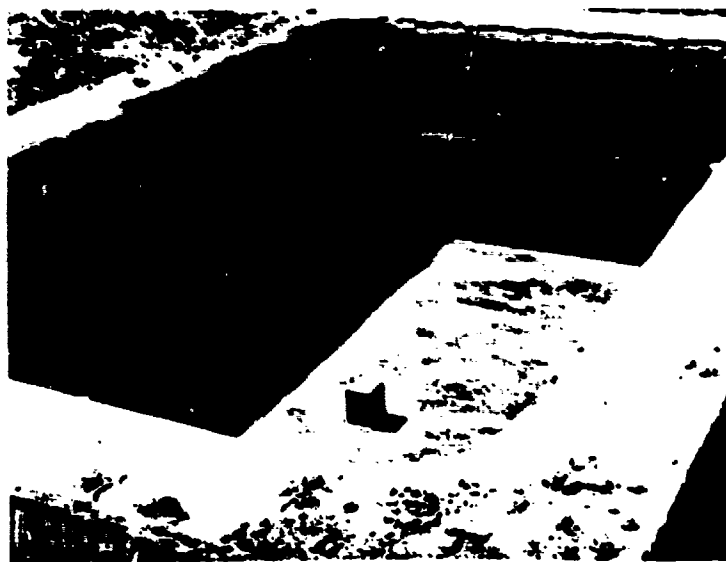


Figure 7. Setup for mine test, showing test plate with crack starter and two frames emplaced.

In some instances, this test is conducted with the armor at low temperature. Cooling the armor plates in a cold temperature cabinet is preferred, but if not available, dry ice can be spread over the plate as in Figure 8. The temperatures of thin plates are measured with thermocouples whose measuring junctions are silver-soldered to the surface of the plate at the approximate locations shown in Figure 9. Tube-type thermocouples are used to measure temperatures of thicker plates to obtain a better estimate of average plate temperatures than surface type thermocouples are likely to provide. Normally, two 6.35-mm (1/4-in.) holes are drilled and tapped with an M8 x 1.25 (1/8 in. in 27 NPT) pipe tap, one in each of two of the plate edges for insertion of the thermocouples. The plate temperatures usually are read from a potentiometer or recording instrument.

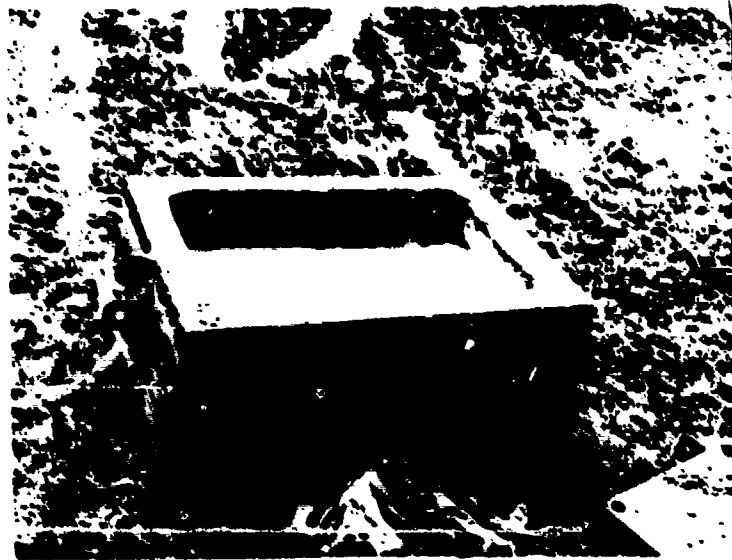


Figure 8. Setup for mine test, showing cooling of plate with dry ice.

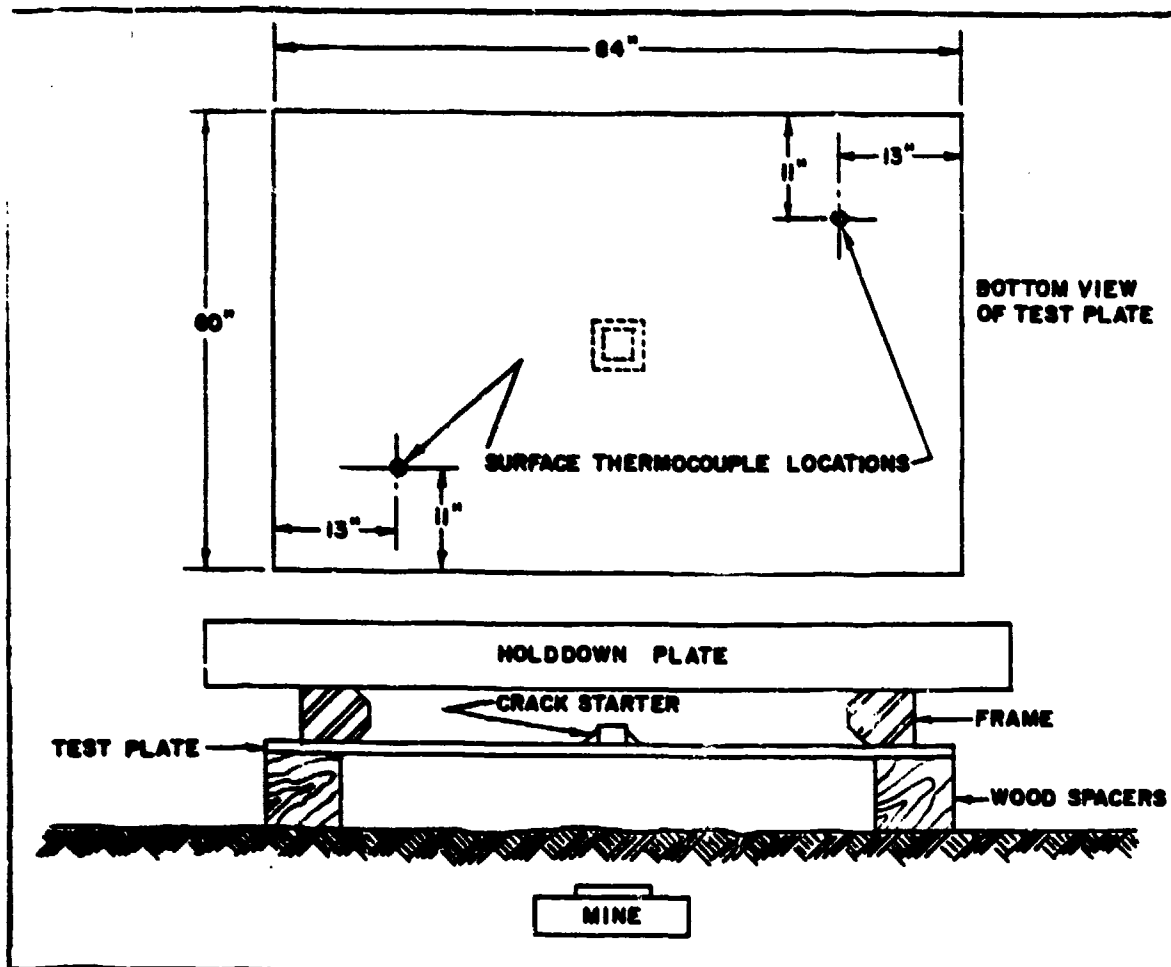


Figure 9. Diagram of setup for mine test of plate.

Floor plate escape hatches can be tested against mine attack by mounting such a hatch in an actual floor plate. Static detonation of the specified mine under the hatch will provide data regarding the adequacy of the hatch design.

5.7.2 Quarter-Scale Tests. When the expense of full-scale mine tests renders extensive investigation of parameters unfeasible, quarter-scale tests can be conducted (refs. 13 and 10p, Appendix J). Typical applications include comparison of one armor material with another, comparison of explosives, and comparison of soil types. Figure 10 shows a typical setup for a controlled soil, quarter-scale mine test. All dimensions of test plate and frame are 1/4 full size. Two-by-fours are used to support the armor plate at a proper height, and a rectangular steel collar (5 cm thick) is placed over the test plate. (The steel frame is not scaled to simulate the dead weight of the vehicle since the evidence (ref. 13, Appendix J) indicates that inertial effects are insignificant.) The reduced charge dimensions are based on the shape of the mine and the density of the explosive. The following equations are applicable to scaling down cylindrical mines such as the M15:

$$\text{Volume of cylinder: } V = \frac{\pi d^2 h}{4} \quad (1)$$

$$\text{Volume in general: } V = \frac{W}{\rho} \quad (2)$$

$$\text{when for comp C4 explosive } \rho = 1.588 \text{ g/cm}^3 \text{ (0.918 oz/in}^3\text{)}$$

Height to diameter ratio:

$$C = h/d \quad (3)$$

$$\text{when for the M15 mine } C = 3/13$$

Solving these equations for h:

$$h = 0.350 (0.420) \sqrt[3]{W}$$

in which:

w = weight of comp C4 explosive in g

h = height of container in cm

Once the height is known, the diameter is computed from equation 3. Composition C4 is a plastic explosive which has the same explosive characteristics as composition B, but has the advantages of being very stable and easily hand-molded. Soil conditions, i.e., type, density, and moisture content, are kept as uniform as possible and are recorded for each mine detonation. Burial depth and standoff distances are also scaled to 1/4 size. After a detonation, the crater depth and maximum and minimum widths at the top are measured. Plate deformation (bulge) is measured in a lengthwise direction and across the plate width. If a crack starter is used, the effect on the plate is evaluated and recorded. Setting up for subsequent rounds consists of first excavating the loose dirt remaining in the crater and filling it gradually with fresh soil. The soil is tamped two or three times as it is filled to ensure a uniform density.

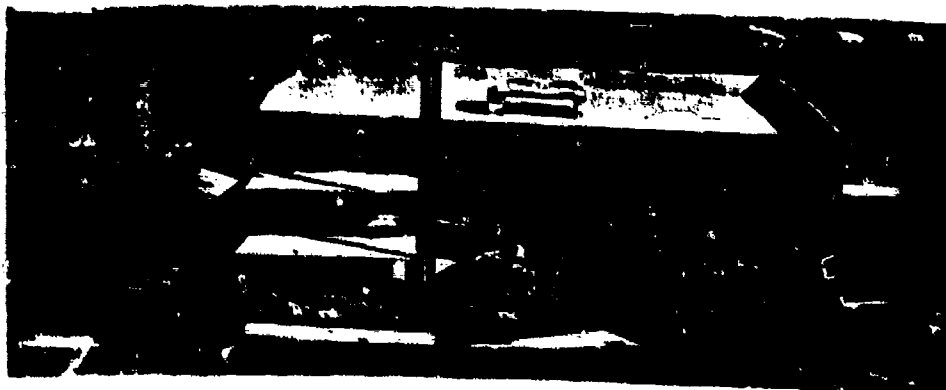


Figure 10. Quarter-scale mine test facility with test plate and hold-down frame in position.

5.7.3 Antipersonnel, Bounding-Type Mines.

a. Lightly armored vehicles are often required to defeat antipersonnel mines 100% of the time. The most severe test occurs when a bounding-type mine, such as the M16A1, detonates against the floor armor (ref. 10f, Appendix J). To conduct such a test requires the following steps:

- (1) Remove the outer canister and the propelling charge from the mine, using remote controlled sawing of the canister from the mine.

- (2) Install the test plate as shown in Figure 9.

- (3) Invert the modified mine and position it vertically in the center of the plate, using wooden wedges to stabilize it and to establish a 13-mm standoff.

- (4) Wire the mine and detonate it statically from a remote location.

- (5) Inspect the plate for damage and record the crack lengths or hole sizes (major and minor "diameters"), depth of deformation, and diameter of bulge.

b. If the mine must be defeated at cold temperatures, the following is performed:

- (1) Prepare the plate for thermocouple temperature readings.

- (2) Install the test plate as shown in Figure 9.

- (3) Cover the plate with crushed dry ice and allow the plate to cool for at least 2 hours, or cool the plate under a carbon dioxide "box" to the desired temperature. If dry ice is used, remove it when the desired temperature

7 February 1984

TOP 2-2-710

has been attained. If the CO₂ box is used, remove it when the desired temperature has been reached.

(4) Continue as at ambient temperature, detonating the mine when the plate has reached the test temperature.

(5) Record temperatures.

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APPENDIX A
CRITERIA FOR ASSESSING A DEFEAT OF ARMOR

1. Damage Basis. Complete and partial penetrations are used in determining a ballistic limit. A complete penetration of the armor is one in which the projectile has "defeated" the armor, as determined by a specified degree of damage. A partial penetration is the result of a projectile impact that causes less than complete penetration; that is, the degree of damage is less than that specified for a complete penetration.

Several methods are used to measure the resistance-to-penetration properties of armor. Each is based on practical considerations and is expressed as the striking velocity of a given projectile causing a prescribed amount of damage. Thus, the amount of preselected damage serves as a criterion for these different measures of damage.

2. Criteria for Complete Penetration. Three criteria (Army, Navy, and Protection) used in evaluating armor have different definitions of complete penetration. These terms are illustrated in Figure A-1.

a. Army Criterion. A complete penetration occurs when a projectile or fragment has penetrated the armor sufficiently to permit the passage of light through a hole or crack developed in the armor, or when the projectile lodged in the armor can be seen from the rear of the plate.

b. Navy Criterion. A complete penetration occurs when the entire projectile or the major portion of the projectile passes completely through the armor.

c. Protection Criterion. A complete penetration occurs when a fragment of either the impacting projectile or the armor has sufficient energy to perforate a sheet of witness material mounted securely parallel to, and 150 mm behind, the test item. the witness material is normally specified as follows:

(1) For steel, titanium, or aluminum armor: 0.4-mm (0.014-in.) thick sheet of 5052 H36 aluminum alloy or a 0.5-mm (0.020-in.) thick sheet of 2024 T3 aluminum alloy (see ref. 10d, Appendix J).

(2) For glass blocks: 0.05-mm (0.002-in.) thick sheet of aluminum alloy foil.

The three penetration criteria represent as many different degrees of critical damage. The Army criterion describes a minimal breach of the armor; i.e., for a complete penetration, the armor must only be penetrated sufficiently to produce a hole through the armor, not necessarily causing any fragments to be displaced to the rear of the plate. The Protection criterion is more severe, as it requires that, for a complete penetration, a fragment of the plate or projectile does a prescribed amount of behind-the-plate damage. The Navy criterion is the most severe, as the major portion of the projectile must pass through the armor to obtain a complete penetration. Resistance to penetration using the three damage criteria will be lowest for the Army, intermediate for the Protection, and highest for the Navy criterion.

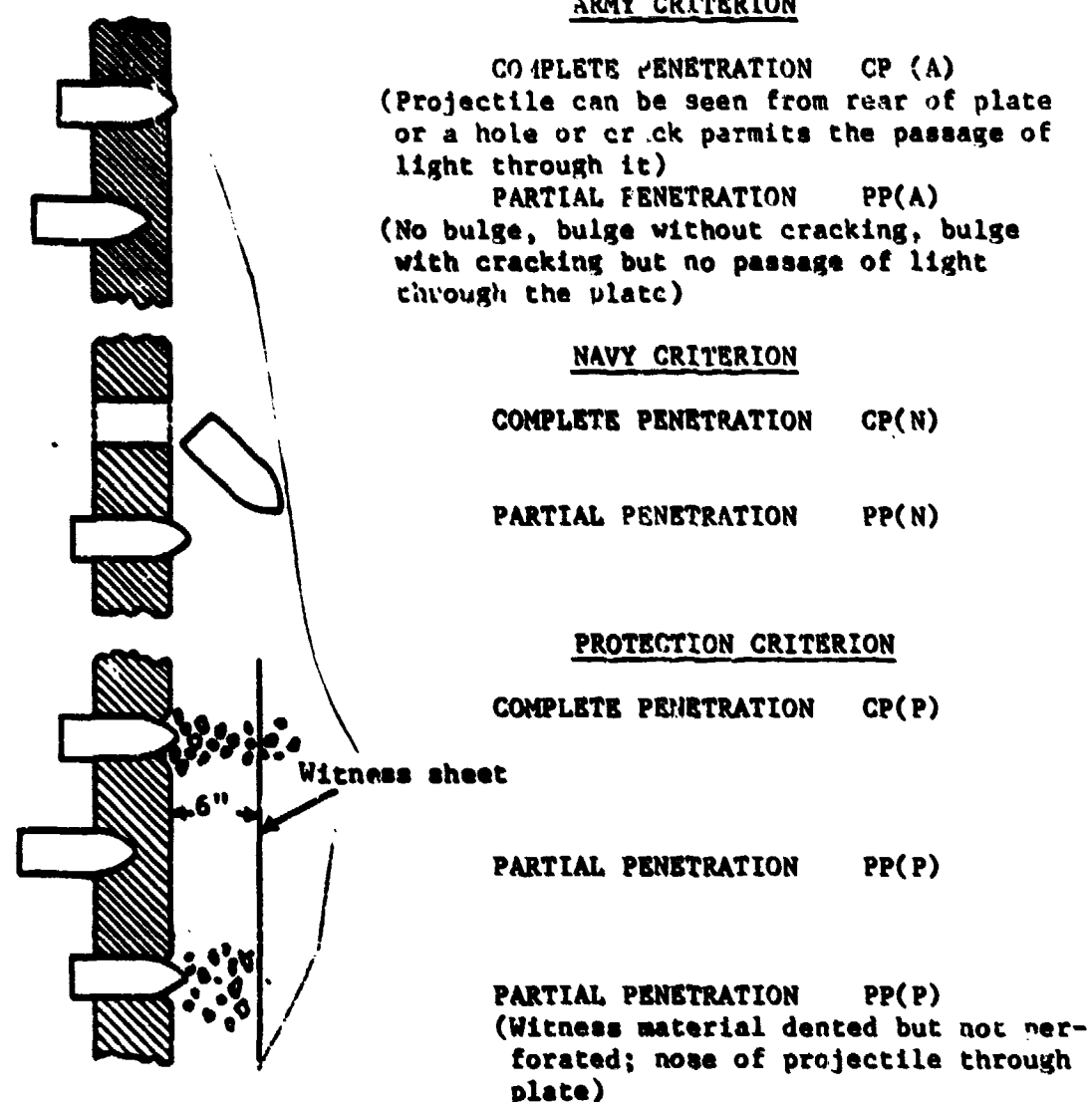


Figure A-1. Partial and complete penetrations of armor under various criteria.

The Navy criterion is especially useful in studying projectiles with explosive fillers. With such properties, the major potential of the projectile is not realized until the projectile has passed through the armor, after which the explosive is detonated. At high obliquities, it is often difficult to differentiate between partial and complete penetrations under the Navy criterion because of projectile breakup. At increasing obliquities, the Army and Protection ballistics limits tend to approach each other. In present practice, the Protection criterion is used for nearly all resistance-to-penetration tests.

APPENDIX B ANGLE OF OBLIQUITY

1. Emplacement of Plate. Firing tests are conducted with the armor plate mounted in a slotted support or "butt" (except when the backup support frame, Appendix G, is used). For firings at other than 0° obliquity, the top of the plate is tilted either toward or away from the weapon, depending upon test requirements and safety considerations. When the plate leans with the top edge toward the weapon, fragments from the armor and projectile are deflected downward, thus reducing the danger from flying fragments and ricocheting projectiles. When photographs of the impact area are required, it is usually preferable to lean the top of the plate away from the weapon to allow more light on the face of the plate.

2. Obliquity of Plate. Obliquity is the angle formed between the trajectory of the projectile at the time of impact and a line normal to the armor surface. There are three varieties of obliquity: vertical, horizontal, and compound.

a. Vertical obliquity is the angle, as measured in a vertical plane, formed between the trajectory and a line normal to the armor surface (fig. B-1). When the gun barrel and the intended point of impact are in the same horizontal plane, and the trajectory of the projectile is essentially flat, the vertical obliquity can be considered equivalent to the angle of the plate from the vertical. Hence, a plate at 60° vertical obliquity will be resting at an angle of 60° from the vertical. Vertical obliquities are usually measured by means of a quadrant with a spirit level. When a plate is placed in the proper slot of the butt (usually 0° , 30° , 45° , or 60°), the obliquity of the target is adjusted so that the angle at the anticipated point of impact by the projectile is accurate with a tolerance of $\pm 0.5^\circ$ (8.8 mils) of arc at 0° and ± 3 mils at 30° , 45° , or 60° .

b. Horizontal obliquity is the angle, as measured in a horizontal plane, between the trajectory and a line normal to the armor surface. Horizontal obliquity is measured with an obliquity stick (TOP 2-2-617).

c. Compound obliquity exists when the armor target possesses both vertical obliquity and horizontal obliquity. Thus, the armor is both tilted away from the vertical and turned partially to one side. Compound obliquities occur frequently in tests of armored vehicles. They can be determined by measuring the angle formed between the trajectory and a line perpendicular to the surface of the armor at the point of impact for each axis and using the following formula (the formula relationship is depicted in the nomograph, fig. B-2):

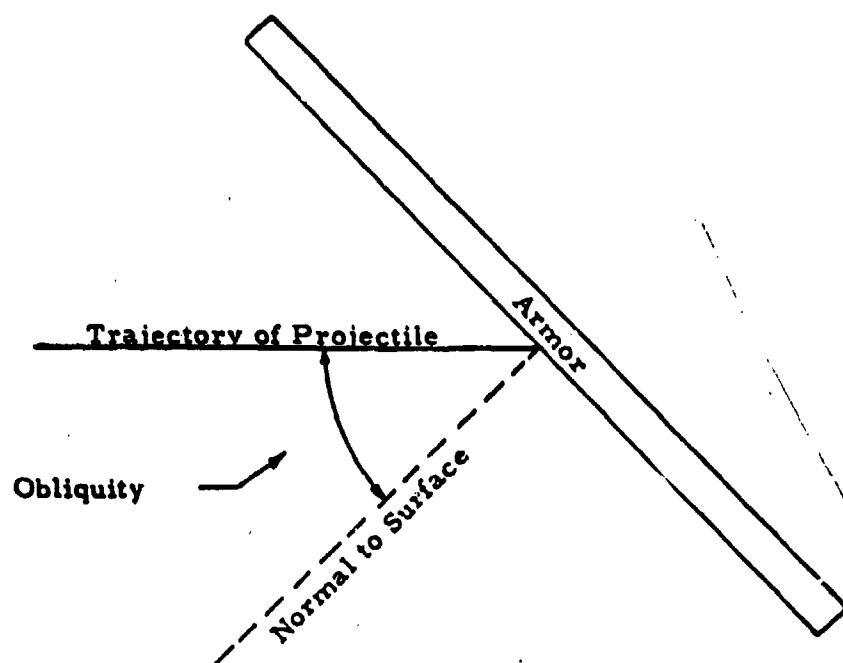


Figure B-1. Obliquity.

$$\cos (\text{compound obliquity}) = \cos (\text{vertical obliquity}) \times \cos (\text{horizontal obliquity})$$

Assuming that the projectile is flying horizontally, a compound obliquity will provide a ballistic limit (BL) equivalent to the ballistic limit of the same plate positioned at an equal single axis obliquity; e.g., BL at 60° compound obliquity equals BL at 60° simple obliquity.

Obliquities are checked only in the area where the projectile is expected to impact. Thus, it is necessary to check obliquity before each round. This operation frequently requires repositioning and rewedging of the plate for each round. An error of 1° when the target is supposed to be at 60° obliquity often results in an error in the BL of 30 m/s or more. On the other hand, a 1° error from 0° obliquity results in a negligible error. The greater the obliquity, the more precise must be the placement of the target.

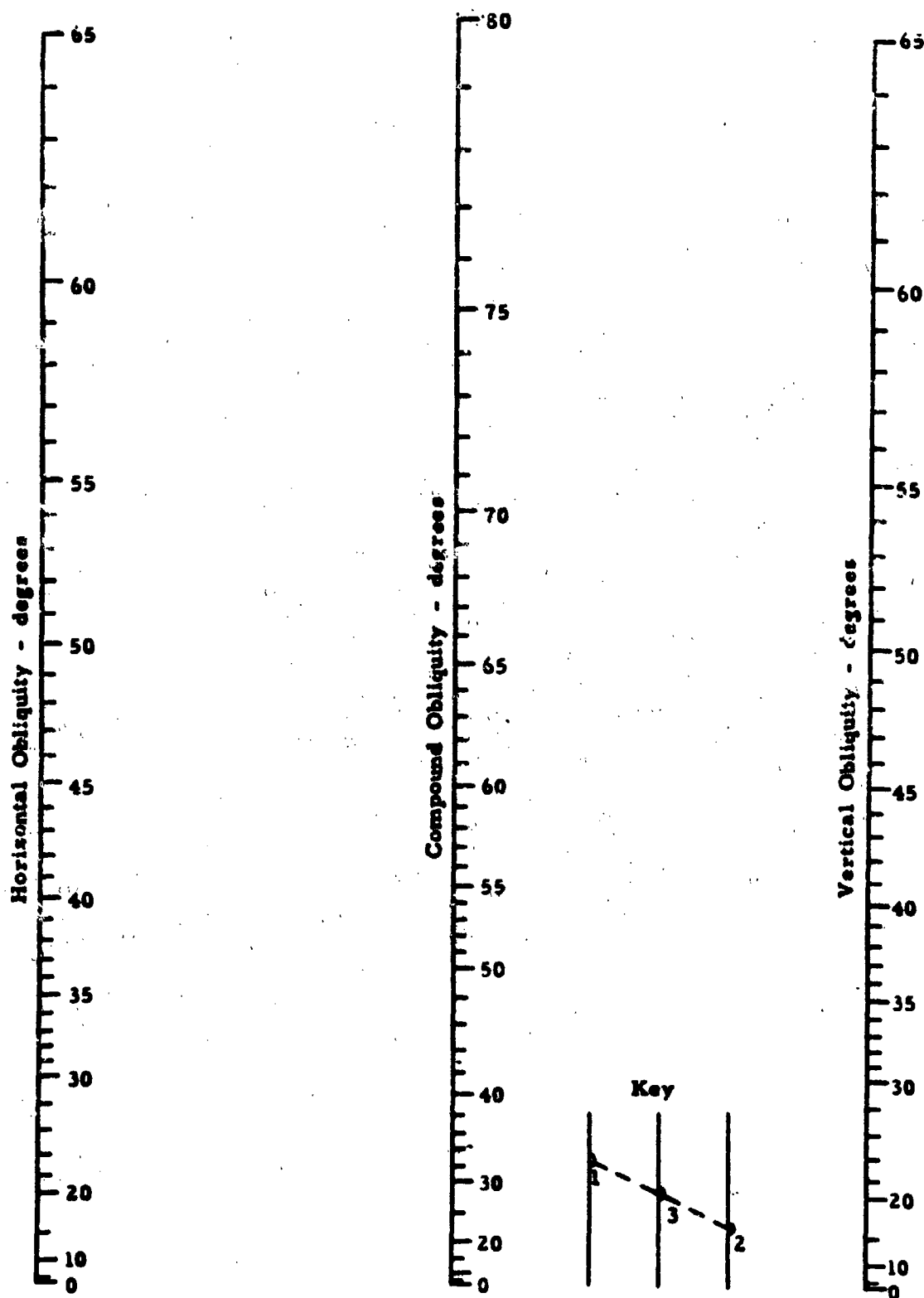


Figure B-2. Nomograph for use in determining compound obliquity.

3. Compensation of Obliquity for Differences in Gun and Target Elevations. When the muzzle of the weapon and the intended point of impact are not in the same horizontal plane (and the obliquity of the plate is measured with an instrument that fixes the horizontal plane), it is sometimes necessary to adjust the angle at which the target plate is resting so that the obliquity of the target is correct with respect to the tube of the weapon. For example, if the weapon is located 30 m from the target and the intended point of impact is 1 m (3 ft) higher than the muzzle, the error in obliquity of the target with respect to the weapon (when the obliquity is measured assuming a horizontal trajectory) is 33 mils or 2° . In this instance, to obtain a true obliquity, the plate must be rotated (top of plate toward weapon) 33 mils. This compensates for the target elevation. For an intended point of impact 1 m lower than the muzzle at 30 m, the angle at which the plate rests would have to be changed by rotating the plate (top) 33 mils away from the weapon. An angle of 1 mil is formed at the apex of two lines that are 0.3 m apart at 300 m (1,000 ft); corrections of this type are therefore easily determined.

4. Compensation for Angle of Fall of Projectiles. If a target can be defeated at relatively low velocities, the range equivalent to the ballistic limit will be considerable. At long ranges, the downward trajectory of the projectiles becomes a factor that would affect penetrating ability, particularly against high obliquity targets. It is not necessary to compensate for this in most tests; if true simulation of range is required, however, the obliquity of the target plate must be adjusted to compensate for the downward trajectory. Such information is usually available for all ranges of interest at Aberdeen Proving Ground.

APPENDIX C
EFFECTS OF IMPACT ON ARMOR AND PROJECTILE

The effect of an impact upon the armor and test projectile is considerably important in evaluating armor. Ballistic limits are greatly influenced, not only by the quality of the armor, but also by the extent and manner in which the projectiles break up on impact. Unusual development in ballistic tests are often explained by armor reaction or projectile breakup. In such cases, the damage suffered by the projectile as a result of each impact should be described on the data sheets. Standard terminology and abbreviations should be used.

1. Effects on Front of Armor. The various effects that the impact of a KE projectile can have on the face of armor plate, together with the standard abbreviation, are listed below. Effects that pertain to each impact are recorded on the data sheets (fig. C-1) immediately after each round is fired. The maximum length and maximum width of the impression in the armor are measured and reported together with a description of the impression. It is sometimes advantageous to record data on a supplementary data sheet (fig. C-2) and to maintain a continuous graphic round-by-round readout of the partial and complete penetrations. A new sheet is used for each firing.

a. Petaling (Pet) - Petaling results from plastic deformation occurring on the face of the plate when low-hardness homogeneous steel armor is struck at low obliquity by KE projectiles. The metal around the penetration is forced outward in leaflike or petal forms as in Figure C-3. In recording petaling, the percentage by which the perimeter of the impression is surrounded by petals is indicated. Example - 75% Pet, 83 by 79 mm (3-1/4 by 3-1/8 in.).

b. Cratering (Crater) - Cratering is a condition in which all of the petals on the face of a plate that has been impacted at low obliquity have been torn loose. Cratering also occurs at moderate obliquities if the projectiles break up greatly upon impact. In wrought homogeneous steel armor, as the hardness increases, petaling gives way to a tendency toward cratering; i.e., various degrees of partial cratering occur.

c. Scooping (Scoop) - Scooping occurs at moderate and high obliquities. The impression on the front of the plate displays a scoop that is indicative of a tendency of the projectile to ricochet.

d. Face Spalling (FS) - Spalling (or scabbing) is a condition in which a layer of armor in the area about the point of impact is detached or delaminated from the armor plate. The maximum length and width of the spall are considered its size. Spalling on the front of the plate is rather uncommon except on face-hardened steel armor. Example - Crater with 75% FS 140 by 160 mm (5-1/2 by 6-3/8 in.).

FIRING DATA SHEET FOR ARMOR ACCEPTANCE ABERDEEN PROVING GROUND, MARYLAND					Firing Record No. Ar-1965		Sh. No. 1 of 1																											
Manufacturer Alumina					Ordered Thick. & Type 1.125		Date of Firing 12 July 1976																											
Specification MIL-A-000008					Plate, Extrusion, Forging No. A12345		Acc. Test Proc. AAA-P/E/F-1																											
Projectile, Caliber & Type 20-mm FS					Projectile Weight 830 Gr.		Propellant Lot No. 35683																											
Firing Obliquity Degr. 0					W.O. No. 321-000-04		Contract No. DA-----261T																											
Rd. No.	Chg. Wt.	Strik. Vel.	Pene- tration	Results - Armor																														
1	240	1550	PP(P) ^a	SB																														
2	250	1642* ^b	P	Pen half out																														
3	257	1710*	C	Exit dia. 7/8" x 13/16"																														
4	251	1653*	P	LB																														
5	257	1708*	C	Exit dia. 7/8" x 13/16"																														
6	251	1659*	P	Moderate Ck on LB																														
7	257	1710*	C	Exit dia. 7/8" x 13/16"																														
<table border="1"> <thead> <tr> <th></th> <th>Avg. Thick.</th> <th>Distances</th> <th>Vel. Meas.^c</th> <th>Range Temperature</th> </tr> </thead> <tbody> <tr> <td>1.122</td> <td rowspan="5">1.125</td> <td>G-1st</td> <td>18.01</td> <td>40°F</td> </tr> <tr> <td>1.123</td> <td>1st-2nd</td> <td>15.00</td> <td>Test Item Temp. 70°F</td> </tr> <tr> <td>1.124</td> <td>2nd-P</td> <td>6.23</td> <td>Signature of Proof Dir.</td> </tr> <tr> <td>1.123</td> <td>Total</td> <td>39.24</td> <td>s/J. Carroll</td> </tr> <tr> <td>1.124</td> <td></td> <td></td> <td></td> </tr> </tbody> </table>										Avg. Thick.	Distances	Vel. Meas. ^c	Range Temperature	1.122	1.125	G-1st	18.01	40°F	1.123	1st-2nd	15.00	Test Item Temp. 70°F	1.124	2nd-P	6.23	Signature of Proof Dir.	1.123	Total	39.24	s/J. Carroll	1.124			
	Avg. Thick.	Distances	Vel. Meas. ^c	Range Temperature																														
1.122	1.125	G-1st	18.01	40°F																														
1.123		1st-2nd	15.00	Test Item Temp. 70°F																														
1.124		2nd-P	6.23	Signature of Proof Dir.																														
1.123		Total	39.24	s/J. Carroll																														
1.124																																		
Typ. Test	Projectile	Obi	Act. Thk.	Req. Vel.	Act. Vel.	Results	Remarks																											
Frag	20-mm FS	0°	1.12	1590	1680	Passed	+90																											
							Spread 68 fps																											
Checked by S.K.			Date 12 Jul 76		Called in by S.K.			Date 12 Jul 76																										

STEAP-DS Form 1, Rev. 18 Jan 64 (Replaces STEAP-DS Form 1, 7 Jan 64)

^aIndicates partial penetration protection criterion.

^bAsterisk indicates velocity used in computing EL.

^cG-1st indicates gun muzzle to 1st screen.

1st-2nd indicates 1st screen to 2nd screen.

2nd-P indicates 2nd screen to face of target plate.

Figure C-1. Firing data sheet for armor acceptance.

7 February 1984

TOP 2-

ROUND-BY-ROUND DATA

Material: 5083-H322

Temp: 72°F

FIRING RECORD NO.

Markings: 722622

Screen Distances:

Size: 1.662 x 12 x 36

Gun - 1st 17.98

DATE: 12 July 1976

Actual Thickness (avg.): 1.66

1st - 2nd 15.01

Obliquity: 0°

2nd - Plate 5.65

Powder: 4759

Gun No.: 300 Magnum M70, Ser. No. 553073

Projectile: Cal .30, AP, M2

Partial Complete

Rd No.	Chg. Grs.	Vel. fps	Re- sults	Remarks
1	36	2502	PP(P)	SB
2	38	2560*	P	MB
3	40	2711	C	PTP
4	39	2630*	C	PTP
5	38	2582*	P	LB with cracking
6	39	2625*	C	PTP
7	38	2575*	P	LB no crack
8	39	2629*	C	PTP

STIMULATED DATA

STRIKING VELOCITY - FEET PER SECOND

2700

2600

2500

*V50 Ballistic Limit (Protection)	2600 fps
High Partial Penetration	2582
Low Complete Penetration	2625
Velocity Speed	70

Figure C-2. Supplementary data sheet.

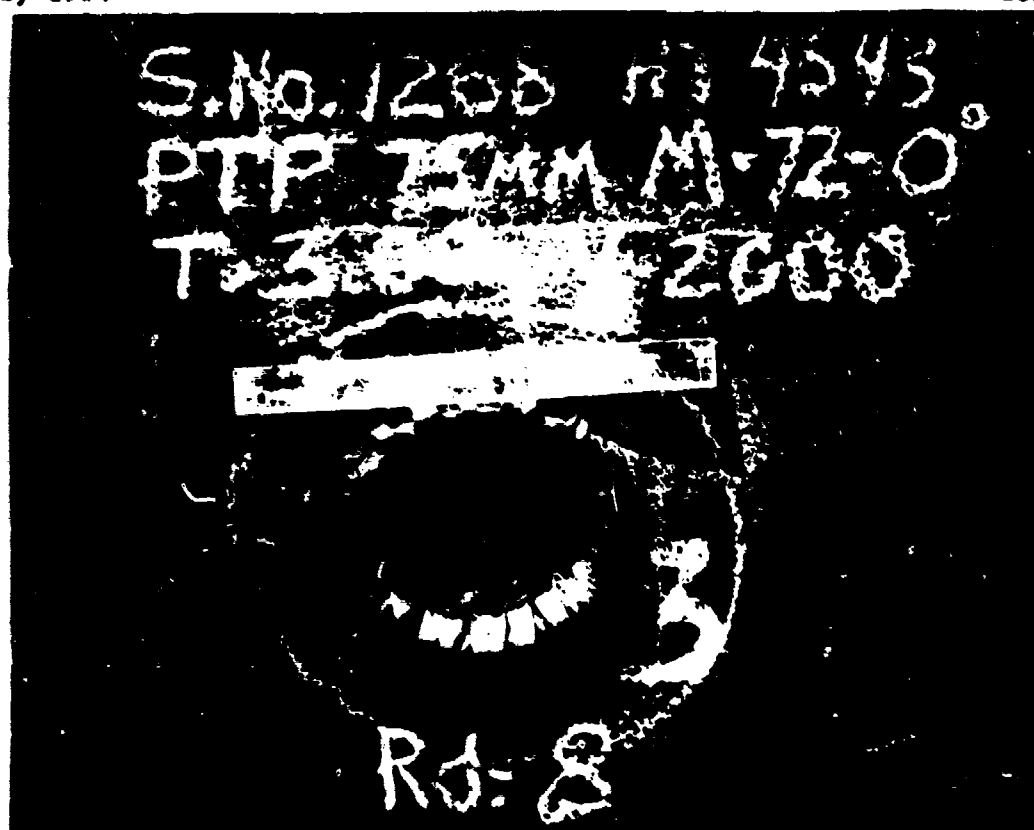


Figure C-3. Petaling on face of steel plate.

e. **Punching (Pun)** - Punching occurs when a circular plug is pushed completely out of an armor plate by the projectile. Punching is an example of pure shear (fig. C-4a).

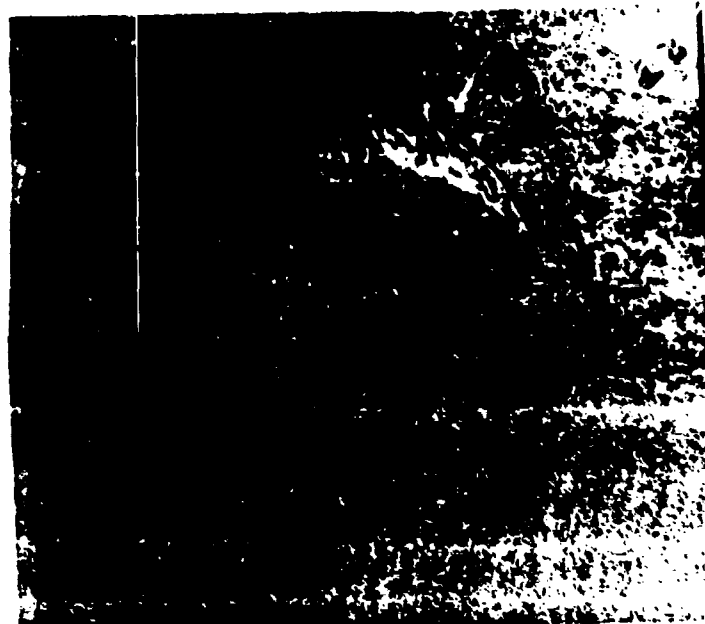
f. **Punching Started (Pun S)** - This is incomplete punching. A plug of armor has been formed and moved, but has not been pushed all the way through the plate (fig. C-4b).

2. **Effects on Rear of Armor.** The various effects that the impact of a KE projectile can have on armor plate as viewed from the rear are listed below. Effects that pertain to each impact are recorded on the data sheet. Sufficient data are recorded to give positive evidence of complete or partial penetration under all three damage criteria. In addition, partial penetrations are described so that the extent to which the partial penetration approaches a complete penetration can be known. Any evidence of armor quality that is indicated should be recorded.

a. **Through Hole (Thru Hole)** - The size of a through hole in the plate is measured in two directions, perpendicular to each other, and recorded. Holes as small as pinholes should be noted, regardless of the criterion being used.



a. Complete punching.



b. Punching started.

Figure C-4. Types of punching.

b. Backspalling (BS) - Spalling occurs more frequently on the back of armor plate than on the front. In steel, it is generally associated with lamination, uncleanness, or lack of toughness in the armor, and poor protection characteristics. Some aluminum alloys used as armor develop spalling under certain attack conditions. In this case, however, the spalling is characteristic of the material, and resistance to penetration is not adversely affected. Maximum width and length of the spall, including any through hole in the plate, together with the percentage by which the perimeter of the exit hole, if any, is surrounded by the spall, are noted (see figs. 3 and 4, para 5.3).

c. Hinged Backspall (Hinged BS) - A spall that has been formed but is still clinging to the plate by one edge is called a hinged spall. Its size is noted on the data sheets.

d. Punching (Pun) - The size of the hole formed by punching is noted. Example - Pun, Thru Hole 76 by 73 mm (3 by 2-7/8 in.).

e. Punching Started (Pun S) - The size of the plug and the distance it has been moved are noted. Example - 76 by 73 mm Pun S moved 32 mm.

f. Fragments Thrown (Frag Thrown) - Whenever fragments are displaced from the rear of the armor, and such information is not clearly indicated by some other standard notation (such as spall or punching), a special notation is made of the fact that fragments were displaced if these data are essential. Information about the number of fragments thrown is described with one of the following adjectives: none, few, some, or many. Example - Thru pinhole with few Frag Thrown.

g. Bulge (B) - Bulges on the back of the plate, behind the point of impact, are noted as follows: no bulge - NB, slight bulge - SB, medium bulge MB, and large bulge - LB.

h. Cracks on Bulge - Bulges formed on the back of armor plate by projectile impacts at or near ballistic-limit velocity generally contain cracks. Some of the more common types of bulge cracks are shown in Figure C-5. A description of the cracking need not be recorded in the data sheets, but the amount of cracking is noted. Cracking is described as slight, moderate, or heavy. Example - Moderate Ck on LB.



TONGUE CRACK
(TCK.)



CIRCULAR CRACK
(1/2 CCK.)



STRAIGHT CRACK
(STCK.)



Y CRACK
(YCK.)



STAR CRACK
(SCK.)

Figure C-5. Typical cracks developed on bulges as a result of partial penetrations.

i. Petaling (Pet) - Petaling on the back of the plate is noted.

j. Plate Crack (Plate Ck) - If, as a result of impacts, cracks develop in areas other than directly behind the point of impact, these cracks are carefully measured and described. This type of crack is referred to as a plate crack. Example - 680-mm (27-in.) Plate Ck from bulge to edge of plate.

k. Unusual Results - Any unusual results, not describable by standard terminology, are discussed in full, and photographs are taken if warranted.

3. Effects of Impact on Projectile. The ability of a KE projectile to penetrate armor depends to a considerable extent upon the projectile's behavior during the projectile-plate interaction. If all the projectiles fly straight and behave in the same way upon impact, i.e., all remain intact or all break up uniformly (in a statistical sense), the projectile-plate interaction can be modeled to the cumulative normal distribution. If, under a given set of attack conditions, some

projectiles remain intact and some do not, an abnormal distribution develops (ref. 10c, Appendix J) and the cumulative normal model will not fit. It is actually possible under some conditions of plate thickness and obliquity for the plate to be defeated at a certain velocity but not defeated when the velocity is increased by 30 to 60 m/s. The reason for this is that at the lower velocity the projectiles remain intact upon impact and penetrate efficiently, but at the higher velocity, the projectiles shatter. Under these conditions, the penetration curve is considered to have a "shatter gap." This is discussed in reference 10c (Appendix J). When such a situation is suspected, the sampling-of-levels technique should be employed in ballistic tests (para 5.1.1.3).

Thick armor, spaced armor, high hardness armor, high obliquity, and high velocity impacts all tend to increase projectile damage. Consequently, some research programs require a careful description of what has happened to the projectile as a result of each impact. Projectiles or projectile pieces that do not pass through the plate are often found on the firing range floor. Those that pass through the plate are usually recovered in Celotex or Maftex sheets stacked behind the plate. Sometimes the fragments are recovered in gelatin. The recovered projectile fragments represent the condition of the projectile after impact. For purposes of description, the projectile is divided into three sections: the nose, the body, and the base (fig. C-6). When sections have separated from each other, each is described separately. The degrees to which the sections are intact are described in the following terms:

- a. Intact - Projectile all in one piece; slight bending can be neglected
- b. Deformed - Badly bent or deformed projectile
- c. Bulged - A projectile that has bulges or shows a tendency to flatten as a result of a low-obliquity impact; typical of ball-type ammunition and low hardness armor-piercing projectiles
- d. Cracked - Projectile cracked but not broken
- e. Fractured - Projectile broken into large pieces (fig. C-6)
- f. Shattered - Projectile broken into many small pieces (fig. C-6)

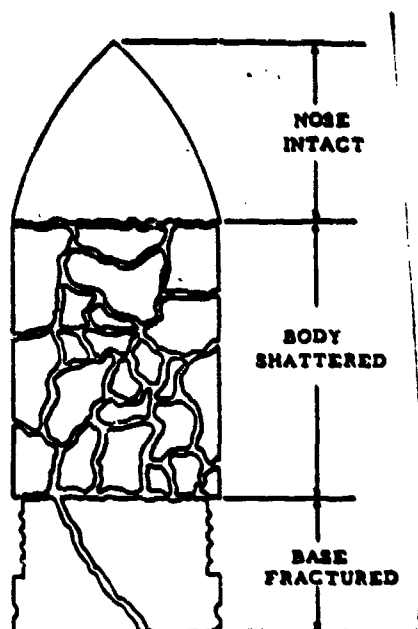


Figure C-6. Representative condition of armor-piercing projectile sections after impact.

In some cases, the attacking projectile is not rejected by the armor plate. When this occurs, appropriate notations concerning what has happened to the projectile are made. Typical notations are:

- a. Projectile Through Plate (PTP) - Entire projectile passes through plate
- b. Projectile in Plate (Proj in Plate) - Projectile remains embedded in the plate. When only one section of the projectile, such as the nose, remains in the plate, a notation is made to this effect.

APPENDIX D MEASUREMENT OF PROJECTILE YAW

1. Background. Projectile yaw is the angular deviation of the longitudinal axis of the projectile from the line of flight. The attitude of the projectile on impact with the target has a direct bearing on its penetration. When a projectile impacts a hard target (metal, ceramic, glass, plastic, etc.) at low obliquity (under 30°), a few degrees of yaw will generally not cause any noticeable change in ballistic limit determinations. When the impact is at 30° obliquity or more, however, yaw can noticeably alter the extent of penetration.

In most testing of armor, projectile yaw does not have to be determined since either the projectile is a widely used projectile that is known to be stable or the target is positioned at 30° obliquity or less. There are three means of determining yaw: by photography, by flash radiography, or by means of yaw cards. Photographic and radiographic techniques are expensive and time-consuming, while yaw cards are simple and inexpensive; thus, yaw cards will be used unless their use proves unsatisfactory. If projectiles of uncertain stability are used, or if a worn weapon barrel is used, yaw cards should be employed at all obliquities over 30° . For projectiles that are believed to be stable, yaw cards should be used for all firings at 60° or greater.

For the usual target (tilted to some vertical obliquity), vertical yaw is more important than horizontal yaw. As a general rule, however, for firings at targets over 30° obliquity, projectile yaw at point of impact of 3° or more is considered unacceptable yaw and the round can be disregarded.

Projectiles that might be susceptible to yaw are those newly designed and those that have a discarding component, such as APDS projectiles. For these types of projectiles and when gun barrels are worn, yaw checks are sometimes made at several down-range locations before any firing against armor takes place. In this way, it is often possible to determine the best location for the plate. When the problem is a worn barrel, it is wise to obtain a new barrel if more than 20% of the projectiles yaw more than 3° at the target location.

Studies of methods for measuring yaw are discussed in reference 10m (Appendix J).

2. Photographic Techniques. A "stop-flight" Polaroid photography technique has been developed by Aberdeen Proving Ground to determine projectile yaw. The following instrumentation and equipment are required (fig. D-1):

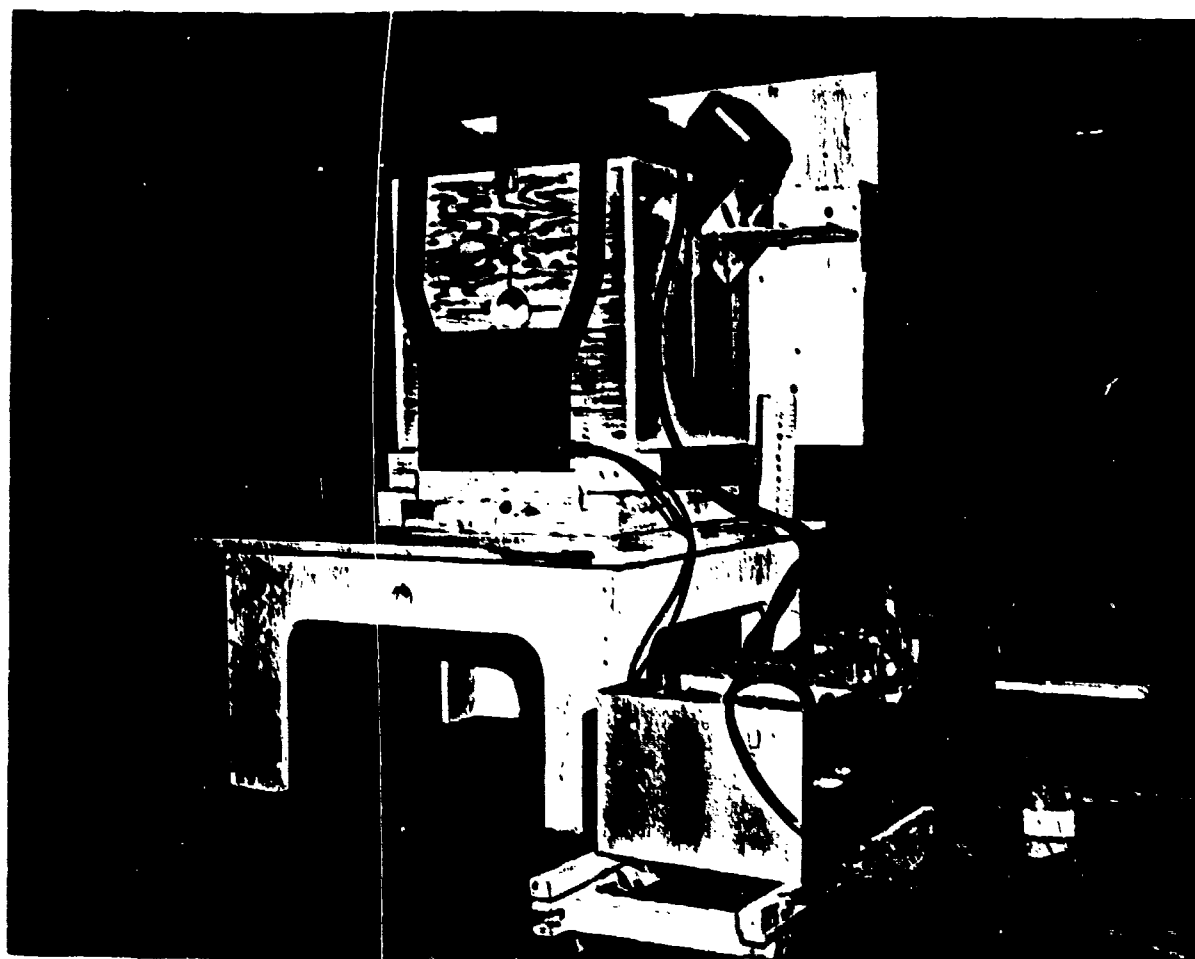


Figure D-1. Polaroid setup for stop-flight photographs of small arms projectiles.

- a. Lumiline screen or printed circuit
- b. Electronic sequential timer with microsecond delay settings
- c. Microflash power supply and flash lamp
- d. Two-speed graphic cameras with model 500 Land camera, 4- by 5-in. backs
- e. Film type 57, ASA 3,000, black and white
- f. Five-inch focal length lens
- g. Specially constructed photographic box

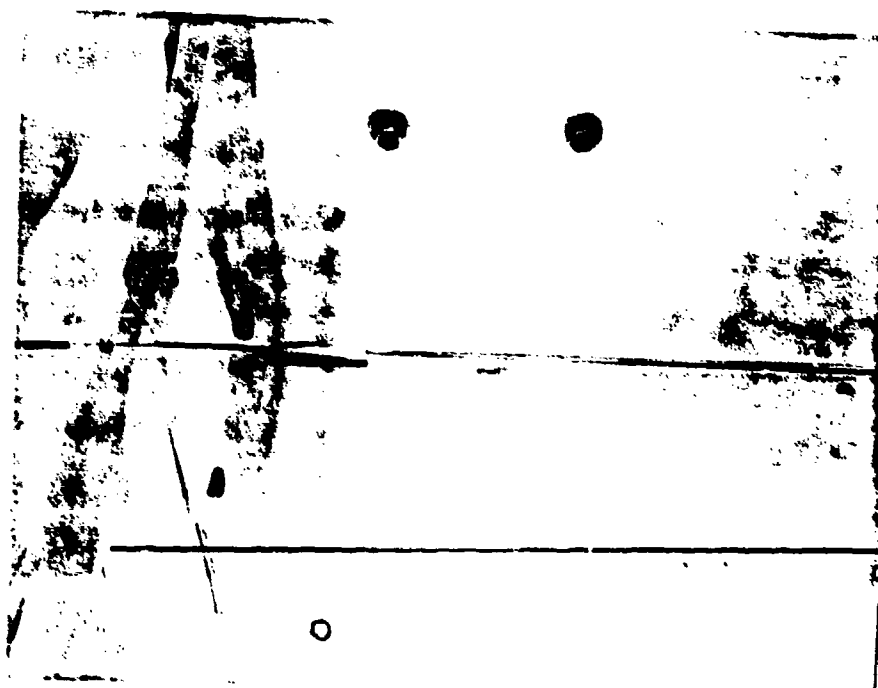
Figure D-2 shows two stop-flight Polaroid photographs taken at 90° angles from each other. This photographic technique can be used for photographs as close as 250 mm (10 in.) from the target plate.

7 February 1984

TOP 2-2-710



a - Right-hand camera view from direction of fire.



b - Left-hand camera view.

Figure D-2. Stop-flight Polaroid photographs of cal .30 AP, M2 projectile.

3. Yaw Cards.

a. Definition. A yaw card is stiff paper-type material placed in the projectile's line of flight. The hole made in it by the projectile is examined to determine projectile yaw.

b. Yaw Card Material and Size. Hardened photographic paper, 200 by 250 mm (8 by 10 in.), is suitable for checking yaw for close-in firing of small arms projectiles. Larger sizes can be used as required.

c. Accuracy. The accuracy of the yaw determination depends upon the quality of the hole made. Clean-cut holes are easy to measure, whereas fuzzy-edged holes are not. An estimate of normal accuracy is $\pm 3/4$ of a degree for small arms projectiles.

d. Yaw Card Setup. A yaw card should be placed several centimeters from the target, just far enough away to avoid projectile and plate fragments. It should be perpendicular to the line of flight.

e. Measuring the Yaw. If the hole in the yaw card is a perfect circle, there is no yaw. If the hole is oblong, the amount of yaw is determined by measuring the length of the major axis of the hole made in the card and comparing this figure with a graph of major axis length versus yaw, which can be prepared for some large-caliber projectiles based on the following formula:

$$\sin y = \frac{\text{length of major axis of hole} - (\text{length of minor axis})}{\text{length of straight portion of side of projectile}}$$

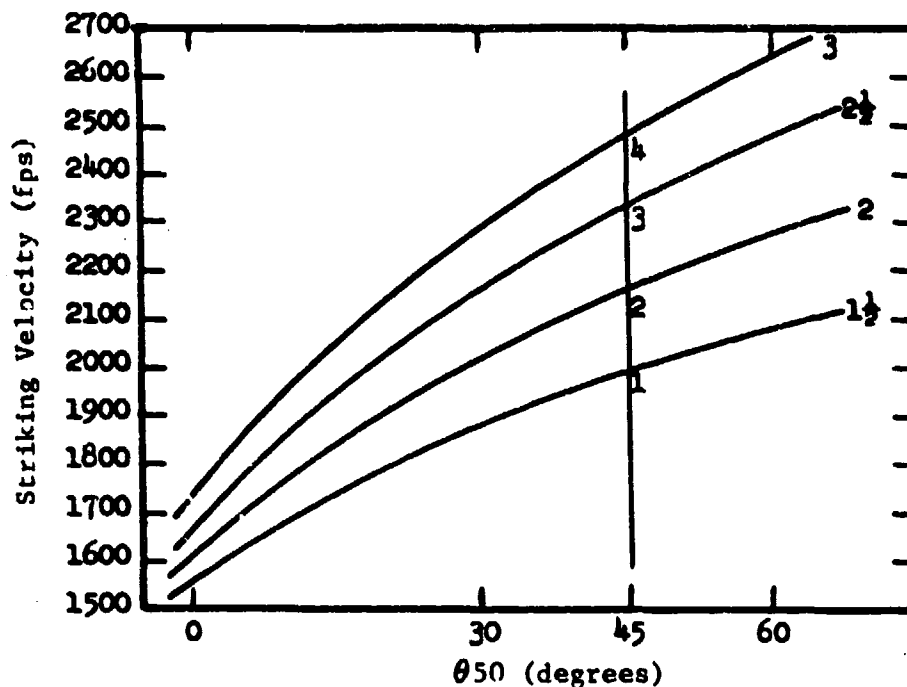
$y = \text{angle of yaw}$

For other projectiles, it is necessary to use a method that involves measurements made in the laboratory using a contour projector. The projectile is positioned on the measuring stage of the projector with a reference line extending through the major axis. It is then rotated in 1° increments about the reference line. Straight edges parallel to the reference line, one on each side of the projectile, are used to determine the maximum-width projections. The dimensions are tabulated relative to the various angles of rotation which are directly correlated to an equivalent angle of yaw. If desired, yaw gages for field use with small-caliber projectiles can readily be made of flat strips of clear plastic or glass. (Gages are not usually made for large-caliber projectiles.) Gages are made for each angle of yaw by inscribing in the strip of plastic (or glass) two parallel lines defining the width representing each angle of yaw. In use, the gages, in turn, are placed on the yaw card until a distance between the parallel lines matches the length of the major axis of the hole in the yaw cards. The angle of projectile yaw is then recorded from the gage.

4. Flash Radiography. This is another means of measuring yaw and is appropriate when the accuracy of yaw cards has proven unsatisfactory and when weapon accuracy of flashes from projectile-plate impact make photography impractical. Flash radiography is described in TOP 4-2-825.

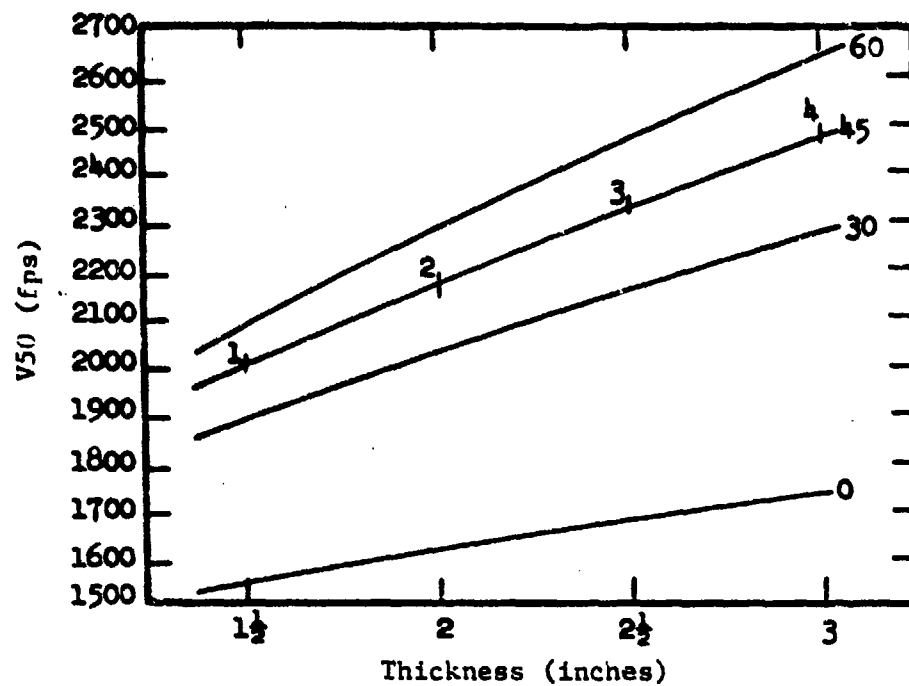
APPENDIX E
CONVERSION OF $\theta 50$ CRITICAL ANGLE TO V50 BALLISTIC LIMIT

Families of curves, Figure E-1a, can be generated from $\theta 50$ critical angles. Each point of these curves is plotted from test data wherein the projectile velocity was essentially constant from round to round whereas the target obliquity was varied from round to round. Each curve is plotted from tests on a specific thickness of plate using a specified projectile. The family of curves can easily be converted to a second family having V50 velocities and thicknesses as coordinates, Figure E-1b. Using selected obliquities from the $\theta 50$ chart, such as 0, 30, 45, and 60°, velocity is plotted for each thickness. A smooth curve is fitted through all points at the same obliquity. The points numbered 1, 2, 3, and 4 on each curve illustrate the method.



a - Critical angle curves from test data.

Figure E-1. $\theta 50$ and V50 curves.



b - Transformed curves: angles to thickness.

Figure E-1. θ 50 and V50 curves.

APPENDIX F BALLISTIC LIMIT PREDICTIONS FROM MODELS

Attempts to predict the resistance of armor to penetration by KE projectiles through the use of mathematical models have been made for more than 200 years. This has included many attempts to develop a mathematical model incorporating armor physical properties factors. Thus far, although approximations are achievable, no method has developed the precision desired to permit a reduction in ballistic testing. In recent years, prediction models based on mathematics and statistical methods alone have been developed. These make no attempt to relate the models to physical properties, chemical properties, or heat treatment. Two models developed at Aberdeen Proving Ground have proven sufficiently precise for use in developing specification minimum ballistic requirements for the aluminum alloy armors, rolled steel, and high hardness steel armors:

a. $V = \sqrt{a + bt}$ (for armor-piercing projectiles)

in which $V = V50$ velocity in fps (m/s)

a, b = constants

t = armor thickness in inches (mm)

b. $V = e^{(a + bt)}$ (for fragment-simulating projectiles per MIL-P-46593A)

The incorporation of accumulated test data in these equations has resulted in average performance curves (ballistic limit versus thickness) computed by the method of least squares, and standard deviations of the ballistics limits about the performance curve. The standard deviations are assumed to be constant over the test thickness range. Table F-1 includes all of the standard deviations that have been computed by this method before 1 January 1973.

Another model, developed for aluminum alloy armor, incorporates tensile strength, elongation, and thickness in a linear equation as follows:

$$V = a + bx_1 + cx_2 + dx_3 \text{ (for cal .30 AP, M2 projectiles)}$$

The values of the constants can be found in reference 10f, Appendix J. The precision of the predictability depends to a large extent of the precision of the input data.

Further details on prediction models are covered in references 7 and 10n.

TABLE F-1. STANDARD DEVIATIONS OF BALLISTIC LIMITS FOR SPECIFICATION TEST CONDITIONS

NOTE: All data based on 6-round protection ballistic limits at 0° except where noted.						
Material	Alloy	Projectile	Approximate Thickness Range	Std. Dev. (fps)		Source (See App. A)
				(a)	(b)	
Aluminum	7039	Cal .30 AP, M2	0.90 to 2.00	40	30	(a) Ltr, 5 Jan 68 (FY 65, 66 data) (ref. 10) (b) DPS-2698 (FY 67 data) (ref. 6g)
		Cal .50 AP, M2	2.00 to 3.35	39	24	
		Cal .50 FS	.70 to 1.00	37	54	
		20-mm FS	.95 to 1.70	52	44	
Aluminum	5083	Cal .30 AP, M2	0.90 to 2.00	29		Ltr, 18 Jan 69 & DPS-2698 (refs. 11 & 6g) (Acceptance Firing Records, APG)
		Cal .50 AP, M2	2.00 to 3.00	44 (est)		
Rolled Steel	-----	Cal .50 FS	.70 to 1.00	48		Refs. 11 and 6g Refs. 11 and 6g
		20-mm FS	.95 to 1.70	55		
		Cal .30 AP, M2	0.23 to 0.60	52		APG-MT-3685 (ref. 6j) Ref. 6j
		Cal .50 AP, M2	.55 to 1.125	52		
		*37-mm AP, M74	1.10 to 2.75	45		APG-MT-3590 (ref. 6i)
		*57-mm AP, M70	2.70 to 4.50	45		
		90-mm AP, M318, A1	4.50 to 6.25	41		
		90-mm APC, M82	2.75 to 3.50	67		
		90-mm APC, M82	3.50 to 5.25	37		APG-MT-3785 (ref. 6k)
		Cal .30 AP, M2	0.130 to 0.330	136		
Rolled Steel High Hard.	45° 30° 30° 30° 0° 0°	Cal .50 AP, M2	.220 to .640	134		
		14.5-mm API, B32	.450 to .760	43		
		Cal .50 FS	.200 to .57	59		
		20-mm FS	.45 to .76	57		

*Standard deviations based on 2-round Army ballistic limits at 0°.

APPENDIX G
SUPPORT FOR THIN PLATES

1. Background. Thin metallic armor plates, mostly 5 mm (3/16 in.) to 6 mm thick, are used in certain combat applications to protect soldiers and equipment. Representative samples are received for ballistic testing. Such plates will probably bend after a few rounds have impacted them in a compact area. Since the ballistic test must be performed at a prescribed target obliquity, frequent changes in plate positioning are required to assure correct obliquity at point of impact. To minimize bending the plate, a rigid backup support has been designed for use in all thin plate ballistic tests that can be conducted within its space limitations. Greater details are provided in reference 10m.

2. The Backup Support Frame. The backup support frame (fig. G-1), of class I rolled steel armor (per MIL-S-12560), was designed to accommodate a 0.3- by 0.9-m (12- by 36-in.) plate. When a plate this size is installed horizontally, four rounds can easily be impacted within any one of the three openings; thus, 12 rounds can be placed along one horizontal line - usually more than enough for the determination of a six-round V50 ballistic limit. The openings are large enough for a row of rounds to be fired at 60° obliquity although a larger frame 0.5 by 0.9 m (18 in.) is available for such tests. On the 0.3- by 0.3-m plate illustrated in Figure G-2, the two rows of rounds are about 76 mm apart. Since the distance from weapon muzzle to target is about 14 m (46 ft), the angular deviation in elevation between the two rows is 1/3 of a degree.

3. Preparation for Firing.

a. Divide the 0.3- by 0.9-m target plate into three equal parts lengthwise, using chalklines.

b. Place the backup support on the test plate holder as shown in Figure G-1.

c. Clamp the test plate in position making sure the chalklines are centered on the supporting ribs.

d. Adjust the target obliquity to the test requirement.

e. Mark (chalk) the location for the first impact. Allow for at least 2 calibers of space between any surface of the support frame and the intended closest approach by a projectile. The first round is to be at the left end of the plate (viewed from the weapon) if the gun is to be traversed to the right from round to round; conversely, to the right.

f. Plan for at least 2 calibers of undisturbed metal between rounds.

g. If some bending of the plate is apparent in the region to be impacted, measure the obliquity with a gunner's quadrant and adjust it if necessary.

h. For tests that will require firing two rows of rounds on the same plate, first adjust the plate to the required obliquity, depress the weapon by 3 mils (assuming a range of 14 m, and fire the first row of rounds; then elevate the weapon to a 3-mil elevation (6 mils between rows) and fire the second row. This procedure will keep the firing obliquity within acceptable tolerance limits.

7 February 1984

TOP 2-2-710

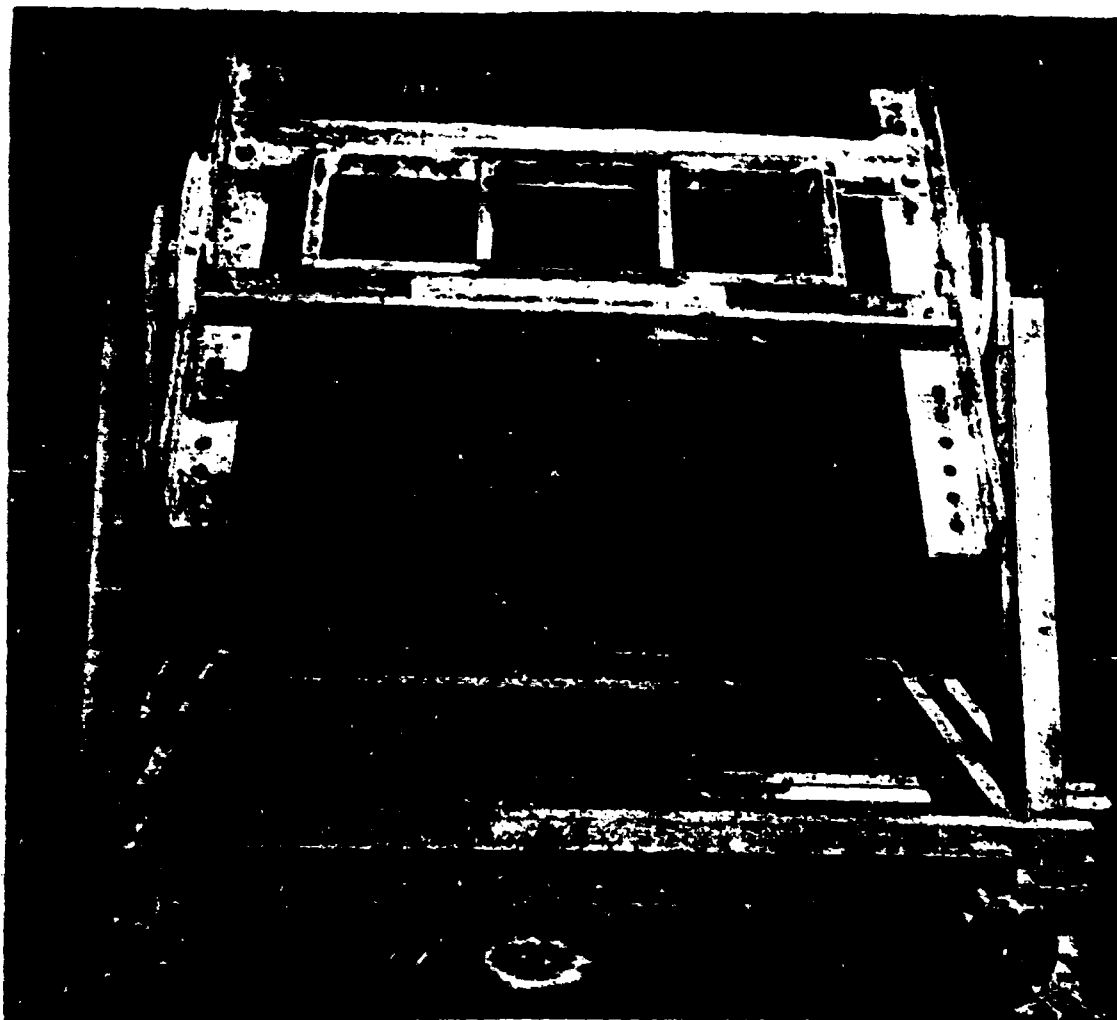


Figure G-1. Thin plate backup support on test plate holder.

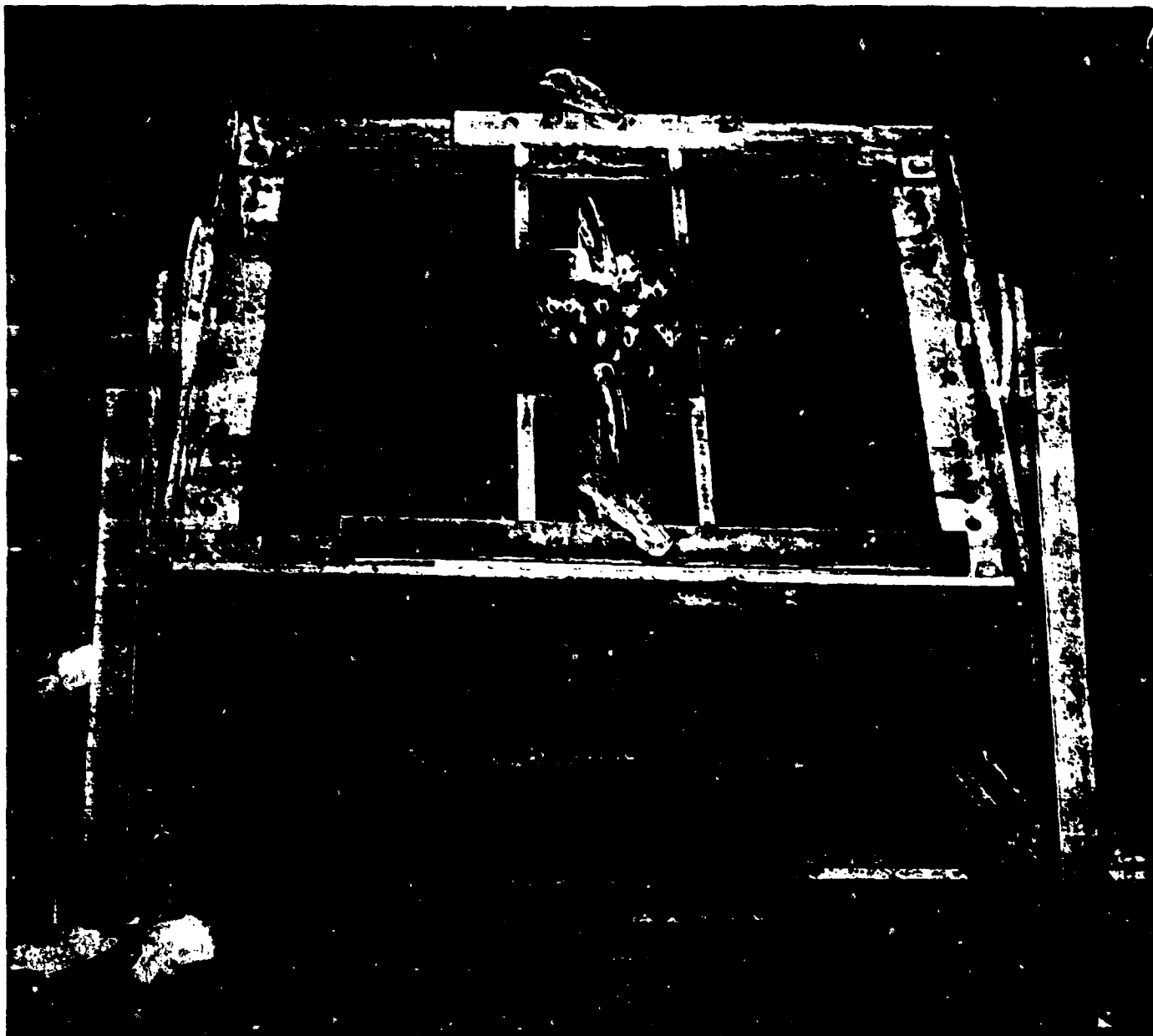


Figure 6-2. Thin plate clamped on center section of backup support frame (after-firing view).

TOP 2-2-710

Ballistic data on armor materials have been generated for many years, particularly by Aberdeen Proving Ground. Detailed information on specific firing programs can be examined at the Technical Library at Aberdeen Proving Ground. Copies of the reports, most of which are classified, can be obtained by personnel having proper credentials from the Defense Technical Information Center, Cameron Station, Alexandria, Va. 22314.

100-mm, APHE, BR412B	122-mm, APHE, BR471	14.5-mm API, B32
90-mm, AP M318	105-mm, APDS, M392E3	14.5-mm API, B541
90-mm, APC, M82	105-mm, AP-T, 182E1	Cal 50 AP, M2
57-mm, AP, M70	105-mm, AP-T, 182E3	
37-mm, AP, M74	105-mm, APHE, BR412B	
	20-mm, HVAP-T, DM43	

PROJECTILE	AAAAAAAAAAAAAAAAAAAA
TYPE 'I'-SPACED ARMOR	
OBLIQUITY (DEG.)	BBBB
REPORT NO.	CCCCCCCCCCCCC
BALL. LIMIT (FPS)	DDDD
ROUNDS IN B.L.	EE
VEL. SPREAD (FPS)	FFF
TEST TEMP. (DEG. F)	GGGG
LC(P) (FPS)	HHHH
HP(P) (FPS)	IIII
COMMENT	JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
PLATE MATERIAL	KKKKKKKK
THICKNESS (IN.)	LLLL
MIL-SPEC	MMMMMMMMMMMMMMM
PLATE HARDNESS	NNN
CHARPY IMPACT	OOO
PLATE ID NO.	PPPPPPPPPPPP
MANUFACTURER	QQ
UNUSED	RR
NOM. THICKNESS (IN.)	SSSS
COMMENT	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
MISC. INFO.	UUUUUUUUUUU

H-1

7 February 1984

TOP 2-2-710

As a byproduct, the system also enables quick determination of whether or not specific test conditions have been fired. Details of the armor data retrieval system are contained in reference 100.

APPENDIX I
PROCEDURE FOR DETERMINING $\theta 50$

1. Introduction. The $\theta 50$ determination for the plate penetration trials is defined as the target obliquity at which there is a .50 probability of the occurrence of either a defeat or a nondefeat of the target with a given projectile and striking velocity. It is obtained by varying the target obliquity for a series of impacts following a statistical procedure of sampling to assure an adequate mixture of responses (defeat of target and nondefeat of target).

A number of sampling procedures can be used to obtain data (see para 5 of the basic TOP). The method described below, however, is the Langlie method.

2. Determining $\theta 50$ by the Langlie Sampling Technique.

a. Fire all rounds at a constant muzzle velocity, either at service velocity or at a velocity to simulate a specific range, as the case can be. If the velocity of a round deviates from the desired velocity by an excessive amount, the round is refired. (Note: Some test programs can require holding propellant weight, rather than muzzle velocity, constant.) Check all rounds for yaw.*

b. For each target, estimate an upper limit and a lower limit angle of obliquity that will provide:**

(1) A very low probability of obtaining a target defeat at the higher angle.

(2) A very low probability of obtaining a target nondefeat at the lower angle.

c. Fire the first round at the target positioned at an angle midway between these two limits.

d. If the first round results in a target defeat, fire the second round halfway between the first-round target angle and the upper limit angle; otherwise, halfway between the first-round target angle and the lower limit angle.

*A round is considered a disregard only if yaw exceeds the established limit for that ammunition or an unfair impact location occurs. When a round is disregarded for yaw or unfair location, another round is fired at the target at the same obliquity and the firing sequence continued.

**It is desirable to select the upper and lower limit angles significantly apart for reasonable certainty that the $\theta 50$ will occur somewhere between them. A 600-mil separation of the limit angles can be reasonable unless there are sound prior data to warrant less separation.

e. If the first two rounds result in a reversal (one target nondefeat, one target defeat), fire the third round midway between the target angle of the first two rounds. If the first two rounds result in two target nondefeats, fire the third round at a target angle midway between the second-round target angle and the lower limit angle. If the first two rounds result in two target defeats, fire the third round midway between the second-round target angle and the upper limit angle.

f. If the first three rounds fired in the sequence result in either all defeats of the target or all nondefeats, select new limit angles and start the firing sequence anew. It can be possible, however, to use one or more of the original three rounds in the final calculation of the $\theta 50$.

g. Fire succeeding rounds using the following rules:

(1) If the preceding pair of rounds resulted in a reversal (one target nondefeat, one target defeat), fire at an angle midway between them.

(2) If the last two rounds did not produce a reversal, look at the last four rounds. If the number of target defeats and nondefeats are equal, fire the next round midway between the target angle of the first and last round of the group. If the last four did not produce equal numbers of target nondefeats and target defeats, look at the last six, eight, etc., until the number of target nondefeats and target defeats is equal. Always fire at a target angle midway between the first and last round of the group examined.

(3) If the conditions in (2) above cannot be satisfied and the last round fired resulted in a target defeat, fire the next round at a target angle midway between the last round target angle and the upper angle limit; otherwise (last round is a target nondefeat), midway between the target angle of the last round and the lower limit angle.

(4) Proceed as in (1) and (2) above.

(5) Terminate firing when 5 successive reversals or 12 rounds have been fired, whichever comes first.

h. When the firing sequence produces a zone of mixed results (the highest angle at which a target defeat occurs is more than the lowest angle at which a nondefeat of the target occurs), use the method of maximum likelihood to calculate the estimate of the mean ($\theta 50$) and the standard deviation ($\sigma \theta$). This is implemented through the use of a computer program. It is assumed that the probability of penetration versus obliquity angle is described by a cumulative normal distribution.

i. Occasionally, the firing sequence will not produce a zone of mixed results (the highest angle at which a target defeat occurs is less than the lowest angle at which a target nondefeat occurs). This is especially so when the number of rounds is small. For this situation, the estimate of $\sigma \theta$ cannot be calculated. The estimate of $\theta 50$ is then calculated by averaging the highest angle at which defeat occurs and the lowest angle at which nondefeat occurs.

3. Example of #50 Firing Sequence. To clarify the firing procedure for #50, the following example of a firing sequence is presented. In this example, the upper limit angle is 1600 mils and the lower angle is 1000 mils.

- Round 1 - This round is fired at a target angle midway between the upper and lower limit angles or 1300 mils. The round results in a nondefeat of the target.
- Round 2 - Based on round 1, the target angle must be reduced midway between the first round angle (1300 mils) and the lower limit angle (1000 mils) or to 1150 mils. This round results in a defeat of the target.
- Round 3 - Based on the reversal of results on rounds 1 and 2 (nondefeat and defeat), this round is fired at a target angle midway between those used for rounds 1 and 2 or 1225 mils. A target defeat results.
- Round 4 - Since the second and third rounds have both produced defeats and no group of four or more rounds is yet available for review, the fourth round must be fired at a target angle midway between that of the third round (1225 mils) and the upper limit (1600 mils), or an angle of 1412 mils. A nondefeat of the target occurs.
- Round 5 - Rounds 3 and 4 have produced a reversal of results (defeat and nondefeat). Round 5 is therefore fired at a target angle midway between those used for rounds 3 and 4 or 1319 mils. A defeat of the target occurs.
- Round 6 - Based on the reversal of results on rounds 4 and 5 (nondefeat and defeat), this round is fired at a target angle midway between those used for rounds 4 and 5 or 1366 mils. A nondefeat of the target occurs.
- Round 7 - Again there is a reversal of results between rounds 5 and 6. Round 7 is therefore fired at a target angle midway between the previous two rounds or 1343 mils. A nondefeat of the target occurs.
- Round 8 - There is no reversal in results between rounds 6 and 7. This is therefore the first time in the firing sequence that it has been necessary to go back to the last group of four or six rounds to obtain an equal balance of defeats and nondefeats (para 2g(2)). The last group of four rounds does not give a balance of results but the last six rounds do (3 defeats, 3 nondefeats). Rounds 8 is therefore fired at a target angle of 1247 mils. This is the angle midway between the angle associated with the first round of the six-round group and the last round of the group (between 1150 mils and 1343 mils). This round produces a target defeat.
- Round 9 - Based on the reversal of results on rounds 7 and 8 (nondefeat and defeat), this round is fired at a target angle midway between those used for rounds 7 and 8 or 1295 mils. A target defeat results.
- Round 10 - There is no reversal in results between rounds 8 and 9. The last four rounds are therefore reviewed for an equal balance of results (defeats and nondefeats) and are found to provide such a balance. Round 10 is

7 February 1984

TOP 2-2-710

therefore fired at a target angle midway between that of round 6 (1366 mils) and round 9 (1295 mils). At 1331 mils round 10 produces a nondefeat of the target.

Round 11 - Based on the reversal of results on rounds 9 and 10 (defeat and non-defeat), this round is fired at a target angle midway between those used for rounds 9 and 10 or 1313 mils. A target defeat is caused by this round.

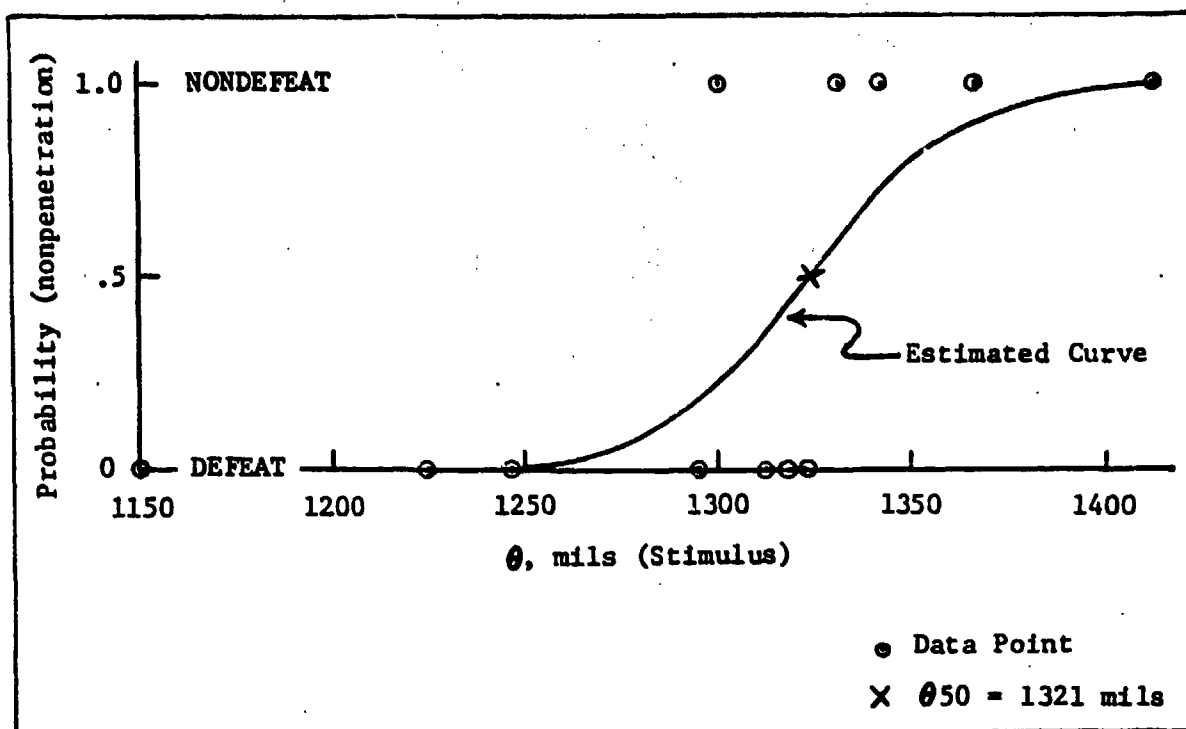
Round 12 - Based on the reversal of results on rounds 10 and 11 (nondefeat and defeat), this round is fired at a target angle midway between those used for rounds 10 and 11 or 1322 mils. A target defeat is caused by this round which terminates this firing series that has produced seven defeats and five non-defeats of the target.

The θ_{50} determined by computer techniques from the data accumulated is 1321 mils. The firing sequence and results for the above example are listed in Table I-1. A plot of the data and a curve based upon maximum likelihood estimates the mean and standard deviation are shown in Figure I-1.

TABLE I-1 - SUMMARY OF θ_{50} FIRING EXAMPLE

Assume: Upper and lower limit angles of 1600 and 1000 mils.

<u>Round No.</u>	<u>Angle (mils)</u>	<u>Target Response</u>
1	1300	Nondefeat
2	1150	Defeat
3	1225	Defeat
4	1412	Nondefeat
5	1319	Defeat
6	1366	Nondefeat
7	1343	Nondefeat
8	1247	Defeat
9	1295	Defeat
10	1331	Nondefeat
11	1313	Defeat
12	1322	Defeat

Figure I-1. Data plot from θ_{50} firing example.

APPENDIX J
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7 February 1984

TOP 2-2-710

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